Volume 11 Number 2

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

FEBRUARY 1927

COLORADO-UTAH SALT DOMES[1]

THOMAS S. HARRISON[2]
Denver, Colorado

ABSTRACT

Several saline anticlines and plugs have been discovered along the Colorado-Utah line. Drilled wells have penetrated several hundred feet of salt, in which appear important showings of oil and gas.

The Pennsylvanian beds are involved. It is believed that the salt beds were deposited in embayments of Lower Hermosan time or older, also that these beds offer ample source rocks.

The domes and anticlines are divided into four groups. The first includes those saline anticlines on which plugs have been developed locally; the second, saline anticlines which have not reached the plug stage but on which local domes have been formed recently, due to differential loading built up by the cutting stream; third, domes not associated with anticlines which also owe their existence to differential loading; and fourth, a structural anticline, called the Meander Anticline, which occupies the Colorado River Canyon and follows that stream in its tortuous meanderings from above Green River, to and beyond it, into the well-known Cataract Canyon.

Attention is given the attempts being made to develop oil and to the possibilities.

The writer also touches briefly upon the igneous phenomena associated with the area.

INTRODUCTION

Hitherto the thought has prevailed that within the United States salt domes were confined to the Gulf Coastal Plain of Louisiana and Texas. The only other recognized salt domes on the American continent were in the Isthmus of Tehuantepec, Mexico, which also touches on the Gulf of Mexico. Salt Domes having similar structure to those in northwestern Europe[3] have recently been recognized in western Colorado and southeastern Utah.

A study of these structures may be helpful in assisting the Gulf Coast student to solve many of his problems. Seldom does one encounter structures so well exposed—what one cannot see in one dome is often revealed in another—but these structures also present conditions involving very difficult problems.

[1] Read before the Association at the Dallas meeting, March, 1926. Paper received by the Editor, November, 1926.

[2] Petroleum Geologist, 707 First National Bank Building, Denver, Colorado.

[3] W. A. J. M. van der Gracht, "The Saline Domes of Northwestern Europe," *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), p. 85.

Within this high plateau region we now know of three basins or embayments of salt deposition, although there are doubtless others. One has been reported by Glen Ruby near the town of Redmond, west of San Rafael Swell in Utah, T. 20 and 21 S., R. 1 E. Here there are two salt and gypsum exposures. Jurassic strata occupy the valley walls. Salt has been mined for years. A second occupies a large area in Colorado, east of the Uinta Basin and west of the Rockies. It may extend from the vicinity of Meeker on the north, southward twenty miles beyond Glenwood Springs. Within this area are exposed several saline anticlines and domes. The third is that to be discussed in this paper. The following very tentative boundary for this saline embayment is suggested:

It was probably limited on the northeast by the Uncompahgre uplift, north by Uinta Basin, northwest by San Rafael Swell, southwest by Elk Ridge Swell, and south possibly by Dove Creek Fold (Fig. 1).

The writer is indebted to Alex. W. McCoy, John Wellington Finch, R. C. Coffin, Harry Aurand, H. W. C. Prommel, H. C. Packard, R. L. Heaton, B. H. Parker, as well as several other geologists with whom he has discussed the problems involved, for their helpful suggestions and information.

GEOLOGY

Within the region is a series of basins separated in part by parallel anticlinal ridges. There is evidence to support the belief that these folds have existed since Precambrian time. They form lines of weakness. Successive cycles of earth movements have accentuated the folds and at the same time deepened the basins between; the greater thickness of sediments has thus been deposited within the troughs.

Our present knowledge indicates that salt and anhydrite were deposited during Lower Hermosan (Lower Pennsylvanian) time. At least two drilled tests have suggested this. Where exposed in all places the gypsum (anhydrite before exposure) has associated with it gray and dark shales and thin limestones. Near Glenwood Springs, below a red sandstone and shale series, possibly in part Pennsylvanian, is a series of dark shales and thin limestones with interbedded gypsum (Fig. 2). This Pennsylvanian series was doubtless laid down under conditions of deposition very similar to those existing in the Moab region during Hermosan time.[1]

STRATIGRAPHY

Within the area erosion has removed practically all beds above the Dakota. This was once covered by Cretaceous and possibly Tertiary. It seems probable, however, in this plateau region, often in motion as it doubtless was, that many beds of the normal thickness were not laid down.

Between the Dakota and the Hermosan is generally a large series of drab, variegated, and red strata. The interior was largely one of deposition in shallow

[1] R. L. Heaton, of the Marland Oil Company of Colorado, and Harry Aurand, of the Midwest Exploration Company, have studied the Glenwood Springs locality. It was upon their suggestions that the writer visited the area during the past summer (1926).

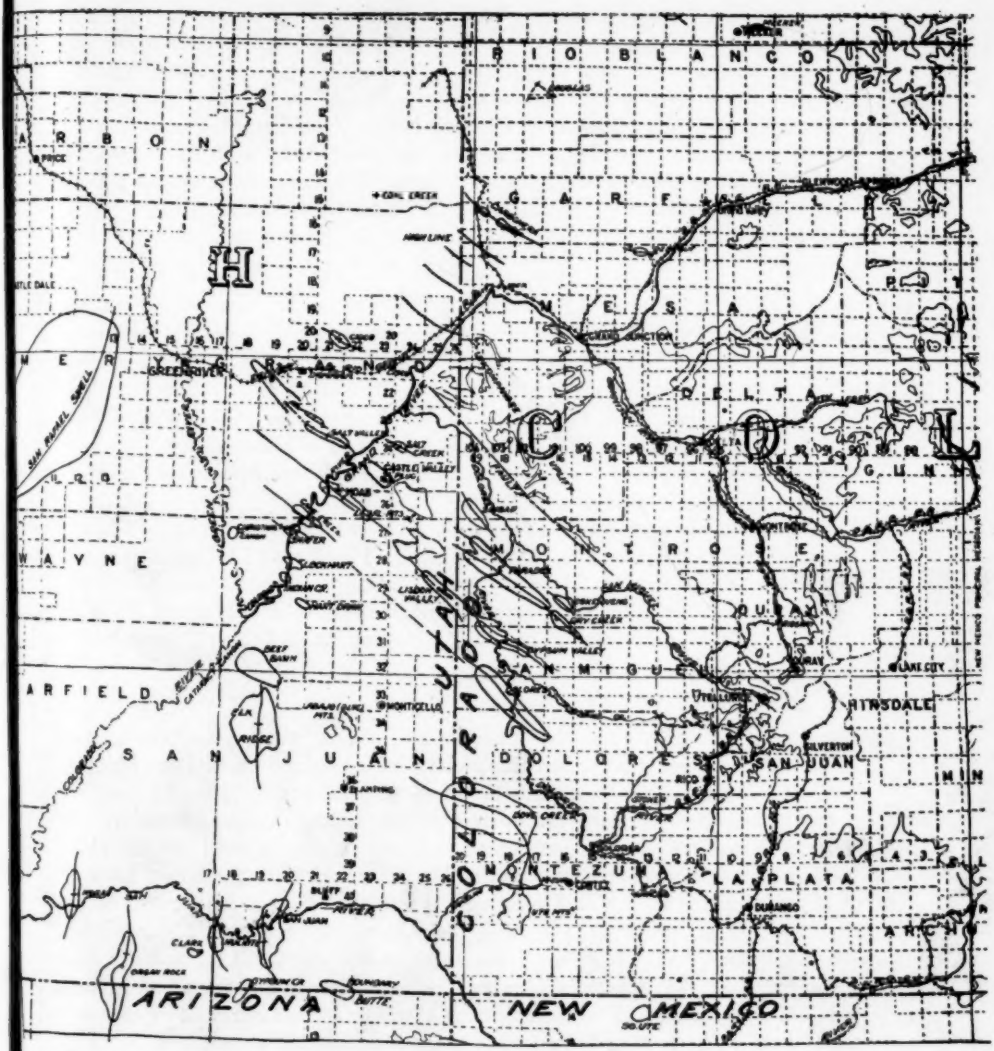


FIG. 1.—Map of Colorado-Utah salt region

lakes and inland seas, in part only connected with the open ocean. Much of the Dolores and La Plata are clearly made up of wind-blown sand. Large unconformities exist at the base of the Shinarump, and earlier, involving Permo-Carboniferous strata. Within the Uncompahgre Plateau at one locality, near Grand Junction, Colorado, a thin section of Dolores lies on Algonkian (Proterozoic) rocks. Whitman Cross and R. L. Ransome show a generalized section for Rico Mountains, Colorado, including Upper, Middle, and Lower Hermosan underlain by a thin series of Mississippian, Devonian, and Cambrian. Of these the Middle, Lower Hermosan, and older rocks are not exposed in the immediate area under consideration.[1]

ANTICLINES AND DOMES

The writer has divided the known saline structures into four groups. In Group I are placed the saline anticlines on which are developed locally salt plugs or stocks. The axes of these structures have an average trend of N. 50° W. They are: (1) Sinbad Valley, Salt Creek, (2) Paradox (including Dry Creek), Castle Valley, Salt Valley, and (3) Gypsum Valley, Lisbon Valley, Moab or Fisher Valley.

In Group II is placed the Dolores-Cane Creek Anticline. On this are the Cane Creek and Shafer local domes.

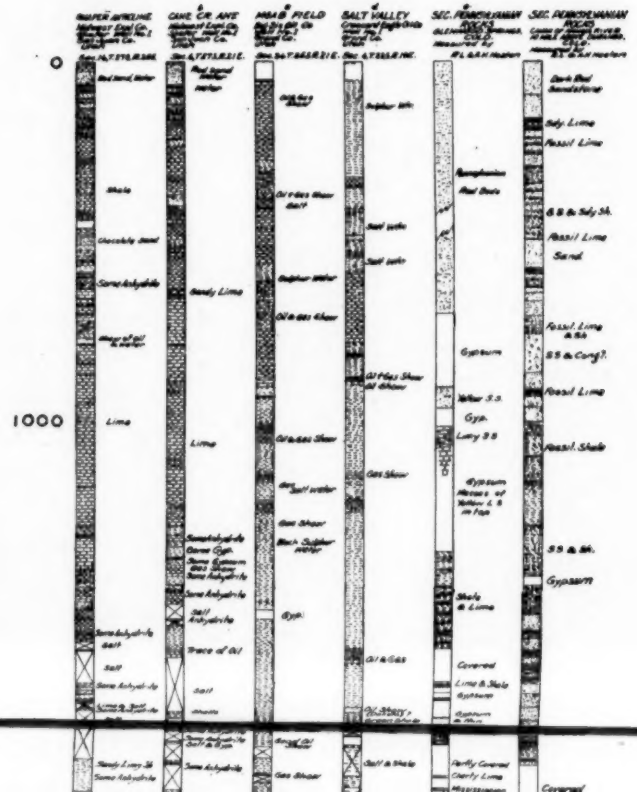
In Group III are known domes apparently not associated with anticlines, namely, Lockhart, Indian Creek, Hart Draw, Beef Basin, and Christmas Canyon. These have no apparent axial trend. Doubtless many others will be found.

In Group IV is classified the Meander Anticline of the Colorado River. Though it is directly related by origin to the third, this remarkable folding is deserving of special consideration.

DISCUSSION

The writer suggests that the principles involved in "salt flowage" are similar to those underlying great diastrophic mountain-building movements and igneous activity. The principles of isostasy are involved in all these effects. Differential loading, though slight, may furnish the stress, and some external movement the impulse. Doubtless the saline structures owe much of their growth to "loading." The weight of superincumbent strata within the trough resting upon the bedded salt has caused it to flow as a plastic mass into the adjacent anticline or other locality of relief. Initially the salt may make its way laterally and upward along bedding plains, joints, or existing fractures. As the volume of the moving salt mass increases, the differential between the loaded trough and the area of relief will become greater. Just so, this differential will be further increased by the erosion of the rising beds and the continued exposition within the troughs. Having started, the activity may continue as long as there is a supply of salt. The Colorado Plateau region would furnish the necessary impulse since it has doubtless been in more or less motion from Precambrian time to the present.

[1] B. S. Butler, "Reconnaissance Geology of Utah," *U. S. Geol. Survey Prof. Paper 111;* R. C. Coffin, *Colo. State Bull. 16;* Cross and Ransome, *U. S. Geol. Survey Folio 130;* W. T. Lee and W. W. Boyer, *U. S. Geol. Survey Press Bull. 6064* (March 30, 1926).


0
1000
Casper Anticline
Sec. 14, T. 31 N., R. 80 W.
Red Sand Water
Shale
Gas Sand
Sandy Lime
Lime
Some Anhydrite
Salt
Trace of Oil
Sandy Lime & Some Anhydrite
Cave Gap Anticline
Sec. 4, T. 31 N., R. 83 E.
Red Sand Water
Sandy Lime
Lime
Some Anhydrite
Some Gyp.
Some Anhydrite
Salt
Anhydrite
Trace of Oil
Salt
Shale
Some Anhydrite
Salt & Some Anhydrite
Hilliard Field
Sec. 34, T. 46 S., R. 21 E.
Oil Sand Water
Oil Gas Show
Oil & Gas Show
Gas Show
Black Sulphur Water
Gyp.
Gas Show
Salt & Shale
Salt Valley
Sec. 4, T. 25 S., R. 19 E.
Sulphur Wtr.
Salt
Salt
Oil Gas Show
Oil Show
Oil & Gas Show
Gas Show
Oil & Gas
Oil Shale
Salt & Shale
Sec. Pennsylvanian Rocks
Sec. 1, T. 24 S., R. 24 E. Salt Lake Meridian
Sandstone
Red Beds
Gypsum
Yellow S.S.
Gyp.
Limy S.S.
Gypsum Member of Yellow S.S. on Top
Shale & Lime
Covered
Lime & Shale
Gypsum
Partly Covered
Chiefly Lime
Sec. Devonian Rocks
Sec. 1, T. 24 S., R. 24 E. Salt Lake Meridian
Dark Red Sandstone
Silty Lime
Fossil Lime
& S. & Silty Sh.
Fossil Lime
Sand
Fossil Lime & Sh.
S.S. & Congl.
Fossil Lime
Fossil Shale
S.S. & Sh.
Gypsum
Covered

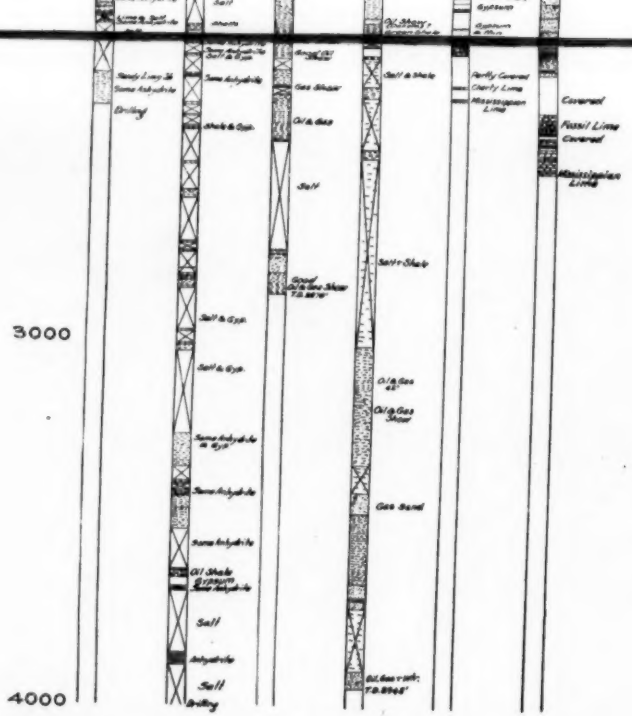

3000
4000
Salt & Shale
Gas Sand
Caverned
Fossil Lime
Caverned
Mississippian Lime

FIG. 2

TABLE I

GENERALIZED SECTION OF FORMATIONS SOUTHEAST UTAH–SOUTHWEST COLORADO AREA

System	Series	Formation	Thickness (in Feet)	Remarks
Cretaceous		Mancos	3,000+	Isolated occurences on north and east border. Fully exposed north of Uncompahgre
		Dakota	200–400	Sandstone, conglomerate and gray-green shale (coal, locally)
		Great unconformity		
		McElmo (Morrison?)	1,000+	Sandstone, gray to white shale near top and variegated near base
Jurassic	La Plata group	Navajo	650+	Gray to yellowish and red to pink cross-bedded sandstone with a shale break 200 feet below the top in places. This same lime mistaken for Todilto
		Unconformity		
		Todilto	75+	Red shale and sandstone. Marine
		Wingate	400+	Prominent massive sandstone. Because of color, often called Vermillion cliff
		Unconformity		
Triassic		Chinle (Dolores)	1,000+	Red sandstone and shale
		Shinarump	100+	Conglomerate and sandstone (Saurian conglomerate)
		Angular unconformity		
Carboniferous	Permian	Cutler:		
		DeChelly	150–200	Red and gray sandstone
		Moenkopie	650+	Red sandstone and shales
		Coconino	800+	Massive gray sandstone not differentiated in Moab area but highly developed at Elk Ridge
		Rico or Supai	0–500	Red sandstone and shale with several purple to red limestone beds
	Pennsylvanian	Upper Hermosan	700–800	Gray fossiliferous limestones interbedded with fine-grained gray sandstones
		Middle Hermosan	800–1,000	Massive limestones, gray and dark. (Exposed San Juan, Utah)
		Lower Hermosan	1,300+	Shale, dark and green. Thin limestones, gray and black. (Not exposed in the area)
Cambrian	Mississippian and Devonian	Ouray	150	Crystalline limestone (not exposed in area)
			200	Thin body of shale underlain by 200 feet of massive quartzitic sandstone (Algonkian) (Exposed in Uncompahgre)

The saline anticlines of Groups I and II, then, owe their existence and development, first, to regional movements which folded the rocks, perhaps as early as

FIG. 3.—Gypsum Hills, Salt Creek plug

FIG. 4.—Salt Creek plug, extending from the extreme left, middle foreground, to the white gypsum, right.

Precambrian time, and later, to the flowage of salt into the crests of those structures.

The writer has much evidence tending to prove that the existing salt plugs (Group I) were developed during Pre-Shinarump time. During that era the moving salt mass raised the superincumbent beds above the surface. They were eroded,

and the salt plug reached exposure. Subsequently, during a long period of subsidence, a great series including Cretaceous and possibly early Tertiary sediments were deposited. Erosion followed. More recently, the Colorado River and its tributaries cut through and reached the salt. Subsurface waters dissolved the upper part of the plug; space was created, and the overlying beds collapsed into it. Collapsed beds occur associated with each of the salt plugs (Fig. 3). Coffin mentions collapsed beds associated with the anticlines in southwest Colorado.[1]

FIG. 5.—A close view of Gypsum Hill. Note thin lime strata at steep attitude.

SALT CREEK, GRAND COUNTY, UTAH

At Salt Creek plug, high-rising gypsum hills have resisted erosion (Fig. 3). The gypsum has been recently in motion; at one locality on the creek, stream gravels have been lifted by gypsum to an attitude of fully 20° above the horizontal.

This plug is characteristic of those seen. Gypsum only is at the surface (Fig. 4). Evidently on exposure anhydrite becomes gypsum and the salt goes into solution. Drilling-wells after reaching a depth of two or three hundred feet report salt and anhydrite with shale and thin lime. At exposure, inseparably mingled with the gypsum, is a broken, twisted, folded mass of shale and limestone (Fig. 5). These rocks have evidently been carried upward by the rising salt (Fig. 6).

Some of the included shales and limestones are petroliferous; of these fragments of limestone picked up at surface on the Salt Creek structure, one ran 30 gallons of oil to the ton, one 10 gallons, and one was barren of oil. Several pieces of hydrocarbon, possibly gilsonite, were found in the wash. A rancher reported a deposit as being a foot or more thick.

MOAB, GRAND COUNTY, UTAH

At Moab a plug has been developed. Several years ago (1919–20), the Western Allied Company drilled in NE. $\frac{1}{4}$ Sec. 12, T. 26 S., R. 21 E. The well was carried

[1] R. C. Coffin, *Colorado State Bull. No. 16.*

to a total depth of 2,450 feet. The log showed shale, lime, gypsum, and salt from the surface to the depth at completion. Near Moab town, exposed on each side of the valley as at Salt Creek, are masses of gypsum which include shale and lime. Continuously along the sides of the valley are remarkable examples of "collapse."

Whitman Cross early recognized the fact that in this vicinity a stratigraphic break of much importance occurs just below the "Saurian Conglomerate."[1]

Three miles northwest of the town of Moab (Fig. 7) along the southwest scarp, about Sec. 26, T. 25 S., R. 21 E., below Shinarump (Saurian) conglomerate, several hundred feet of Cutler overlie 300 feet of Rico, which in turn normally overlie Upper Hermosan. Just west of the town in Sec. 34, T. 25 S., R. 21 E., a scant 100 feet of Cutler lies upon an Upper Hermosan member fully 350 feet below the top of that series. Not less than 1,200 feet of the series seen at the first locality, known as "dug way," is missing. In Figure 7 the "dug way" is at the extreme right. The lower prominent bed seen descending the scarp from right to left is the Shinarump. The beds are being wedged out. The salt plug occupies the valley and should have its greatest development within the area to the left of the picture. There the Western Allied well was drilled. The fault plain occupies the face of the scarp. Note that it dips inward toward the valley. The salt mass thus appears to be wedge-shape and narrowing downward.

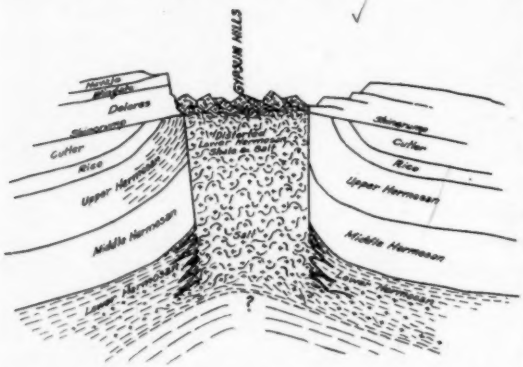


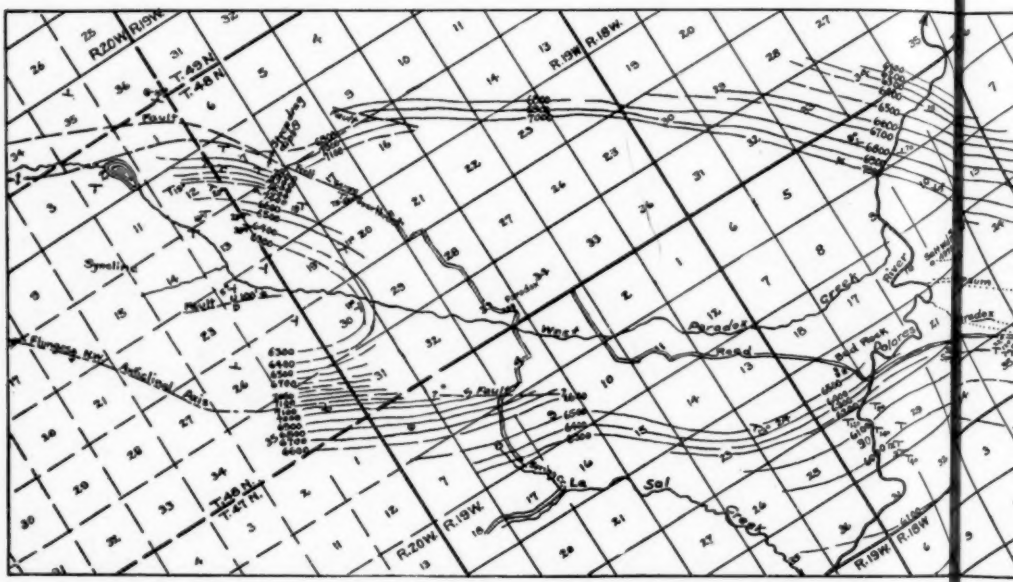
FIG. 6.—Idealized section of salt plug as it exists at Paradox, Sinbad Valley, Castle Valley, Salt Creek, Moab, and Salt Valley. At many of these localities the plug is in part overlain by collapsed red beds of Cutler, Dolores, etc.

The Big Six Oil Company well, Sec. 34, T. 25 S., R. 21 E., was drilled in 1921–23. The well is located on the flank of the salt plug. It commenced several hundred feet below the top of the Upper Hermosan (Fig. 2c), and appears to have reached the Lower Hermosan shale series at about 900 feet. Several showings of oil were reported, and thin beds of salt were encountered. The largest, 300 feet in thickness, was from 2,450 to 2,750 feet. In the section there was a noteworthy lack of sands.

PARADOX, MONTROSE COUNTY, COLORADO

At Paradox (Plate 2) two wells have been drilled. One, the Cinco Minas (SW. ¼ Sec. 4, T. 46 N., R. 17 W.) reached a depth of 3,700 feet, and the second,

[1] Whitman Cross, "Stratigraphic Results of a Reconnaissance in Western Colorado and Eastern Utah," *Jour. Geol.*, Vol. 15 (1907), p. 634.



STRUCTURE MAP OF PARADOX VALLEY, MONTROSE COLORADO

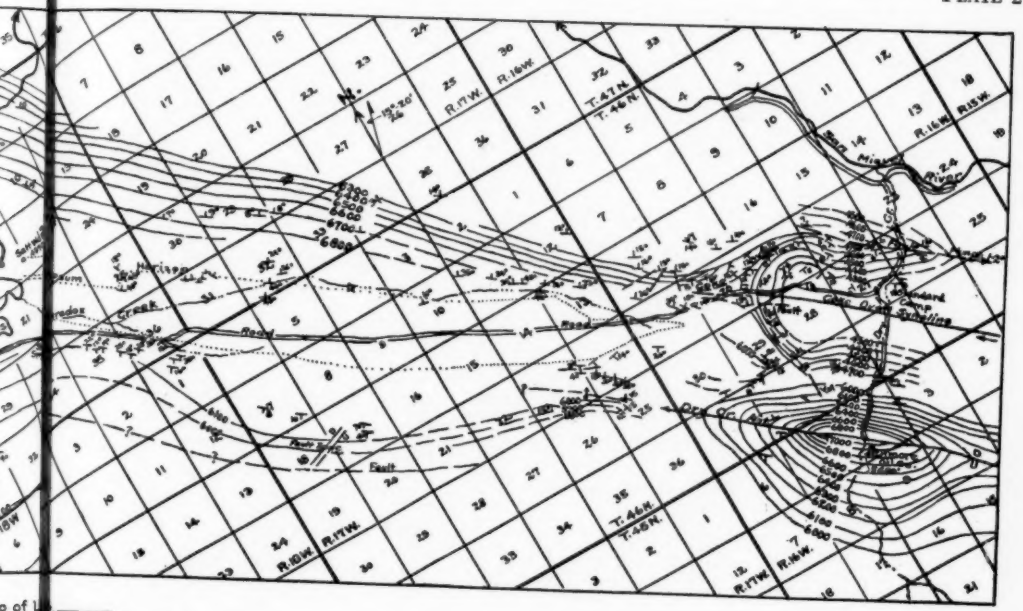

T. 47 N.
T. 46 N.
R. 16 W.
R. 17 W.
R. 15 W.
Fault
Creek
Road
Mine
Camp
Gas Well
Oil Well
Dry Hole
Salt Water Disposal Well
Abandoned Oil Well
Abandoned Gas Well
Proposed Location
Proposed Gas Well
Proposed Oil Well
Proposed Salt Water Disposal Well
Proposed Abandoned Oil Well
Proposed Abandoned Gas Well
Proposed Dry Hole
Proposed Abandoned Salt Water Disposal Well
Proposed Abandoned Dry Hole
Proposed Abandoned Location
Proposed Abandoned Gas Well
Proposed Abandoned Oil Well

FIG. 7.—The southwest scarp of valley northwest of town of Moab, Utah. Photograph by A. J. Hazelwood

General Petroleum of California (in Sec. 35, T. 48 N., R. 19 W.) is at 2,200 feet; both were in salt throughout. In each, the writer is informed, there appeared to be more shale and lime in the first 1,400 feet than below. At Paradox, then, the salt flow has not proceeded far enough to expose fully the "caught up" shale mass to erosion. This circumstance was suggested by observation at Salt Creek and at Moab. The Western Allied well also reported more shale in the upper than in the lower part of the log.

The Paradox wells reported several showings of paraffin oil and gas. The gas, however, contained so much carbon dioxide that it would not burn freely.

DRY CREEK, MONTROSE COUNTY, COLORADO

Southwest along the Paradox fold and largely in T. 45 N., R. 16 W., is the Dry Creek Dome. At the crest Dolores beds occupy the surface, and higher beds including Mancos shales are in the flanks. A well drilled by the Gilmore Oil Company in the SW. ¼ Sec. 4 did not reach the salt plug, which the writer believes to exist, though it was drilled to 2,700 feet. A fault with 200 feet of vertical throw and striking about N. 50° W. cuts the crest of the dome. A small gypsum mass (see left foreground, Fig. 8) appears at the surface on the fault. It doubtless originated in the salt mass below.[1]

Here within the adjacent synclines an immense thickness of strata, including Mancos shale of Cretaceous above, rests upon the Lower Hermosan salt beds. It is not surprising that salt in the plug has sought relief from the stress of this great load.

LISBON VALLEY, SAN JUAN COUNTY, UTAH

At Lisbon Valley, along the axis of the anticline, strike faulting has brought Mancos shale (Cretaceous) in contact with Upper Hermosan. Harry A. Aurand, who has given much detailed study to the region, has estimated that the apparent vertical throw is close to 5,000 feet. The writer suggests that a full section of beds was not laid down.

R. C. Coffin recently informed the writer that near the northwest end of Gypsum Valley in Colorado, southeast from Lisbon Valley, a thin section of 100 to 150 feet of Upper La Plata is in contact with the exposed gypsum of the plug. In his *Colorado State Bulletin No. 16* he shows, in a section made farther southeast across Gypsum Valley, La Plata in contact with Carboniferous. That a full section of beds was not deposited is further suggested by the history of the Crescent Eagle well drilled in 1925 in Sec. 4, T. 22 N., R. 19 E., on the Salt Valley Anticline (Fig. 9).

The well (Fig. 2*d*) started in Mancos shale within evidently collapsed beds. The strata encountered were almost impossible of correlation, though it is suggested that Dakota may have been reached at 1,810 feet. Below it green clays and sands of probable McElmo were reported. Salt was encountered from 2,077 feet on. The well reached a total depth of 3,900 feet, encountering shale and salt to the

[1] H. C. Packard brought this to the attention of the writer.

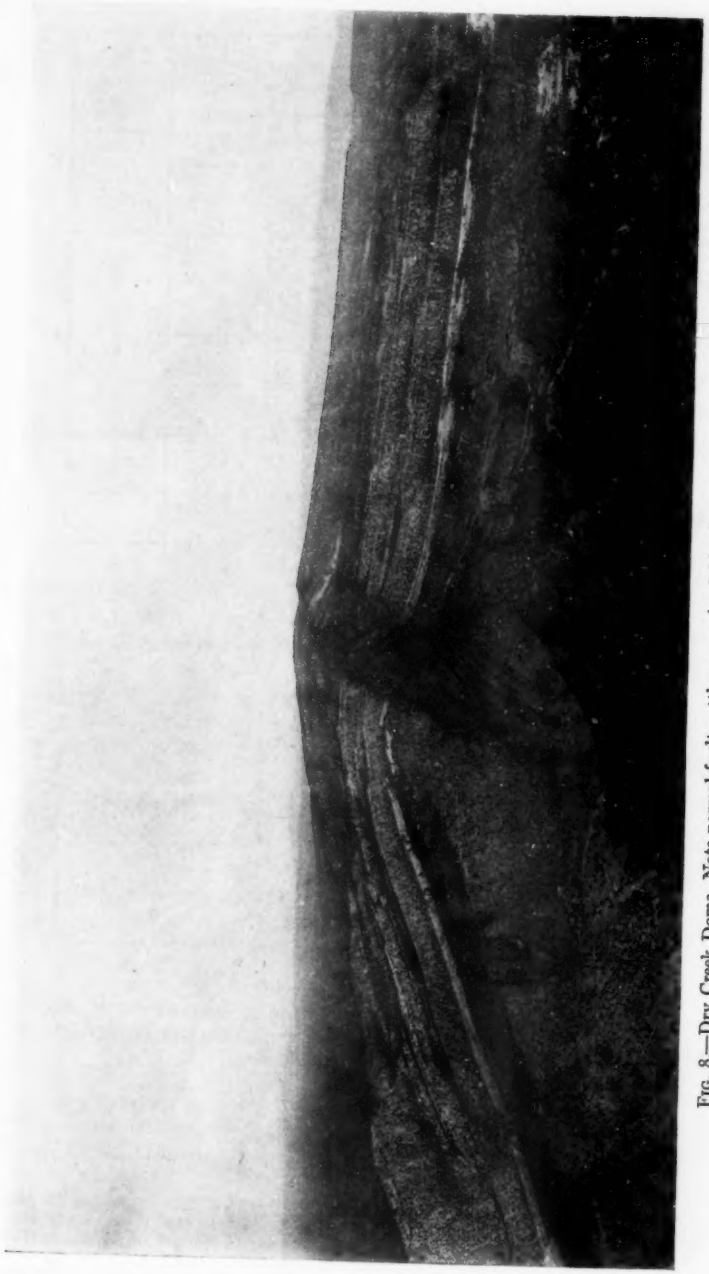


FIG. 8.—Dry Creek Dome. Note normal fault cutting crest (on left); also gypsum deposit fault (left foreground)

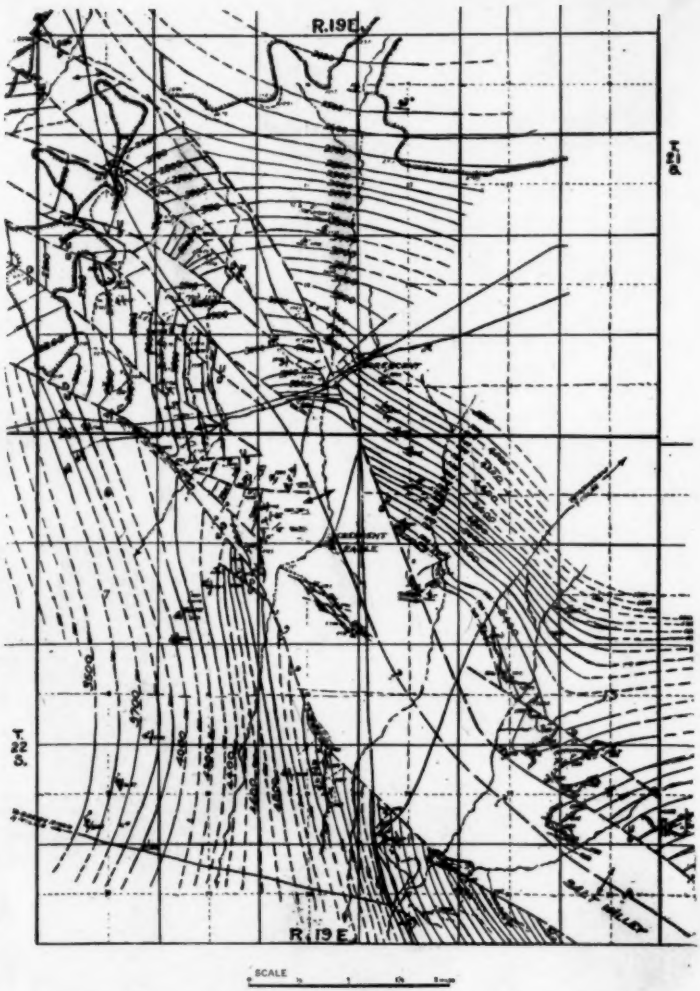


FIG. 9.—Map of Crescent Area, Grand County, Utah. Prepared for the Midwest Refining Company (Carroll H. Wegemann, Chief Geologist) by Frank G. Evans, Jr., assisted by A. W. Weeks under the supervision of R. C. Coffin, September-October, 1924.

Explanation

Datum bed

Base of lowest Mesaverde Ss.

Meeker sandy horizon

Dakota Ss.

Explanation

Conglomerate and Ss. at top of McElmo

Concretion beds and other beds traced

Calcite veins and faults of unknown displacement.

Contours on sandy horizon 700 feet ± above Ferron Ss. Interval, 100 feet. Sea-level elevations.

end. It is interesting to know that considerable potash was reported below 3,280 feet.[1] No Red Beds are shown in the log. While not conclusive, the circumstance suggests that the well found no La Plata, but went from McElmo into the salt plug. Lisbon Valley is a northwest continuation of the Gypsum Valley saline. Based on the additional evidence, the writer suggests that a buried salt plug also exists at Lisbon Valley and that the rising salt mass maintained exposed position throughout a long period of Post-Pennsylvanian time when there was no deposition of beds. The beds on the Mancos (northeast) side of the fault have settled—collapsed—into space above the salt. The actual is, however, much less than the apparent "throw."

CANE CREEK AND SHAFER DOMES (GROUP II)

The Cane Creek and associated domes of Shafer, Lockhart, and Indian Creek were first reported by Prommel.[2]

At Cane and at Shafer the Midwest Exploration Company are now drilling (October, 1926). Both wells are located on prominent local domes and both started in upper strata of the Upper Hermosan. The former encountered more than 3,000 feet of salt below 1,500 feet (Fig. 2*b*). Its present depth is below 4,600, drilling in anhydrite and salt with some shale. The latter well is drilling at 2,350 feet; it encountered the salt at 1,610 feet (Fig. 2*a*).

In November, 1925, there was reported from the Cane Creek well a large find of oil and gas with salt water in lime at 2,028 feet. The "lime" proved to be normal; the oil was of paraffin base and 37° Baumé gravity. There were 800 pounds of pressure. After months of unsuccessful effort to make a producer, drilling was resumed.

The Cane Creek Dome is a strong structure showing fully 750 feet of closure. Both Cane Creek and Shafer appear to be on the Dolores-Cane Creek regional anticline (Fig. 1). Mr. Prommel has kindly allowed the writer to use his original structure map (Fig. 10). On this it may be noted that the Colorado River, strange to say, cuts the crest not only of Cane Creek but also that of Shafer and Lockhart; and it is but slightly off the surveyed crest of the gentle Indian Creek Dome. With the single exception of Cane Creek, the doming does not extend beyond the canyon walls. The Cane Creek sharp folding follows up the winding canyon of Cane Creek (hence its name) for several miles southeastward.[3] That a stream should cut the crest of one dome might not be considered a peculiar circumstance, but that it should apparently seek out the crests of several in succession is, to say the least, noteworthy.

The writer suggests that these domes were not in existence when the dissection

[1] A company has been formed to test the vicinity further for potash.

[2] H. W. C. Prommel, "Portions of Grand and San Juan Counties, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), p. 384.

[3] B. H. Parker, Geologist of the Marland Oil Company of Colorado, in personal communication.

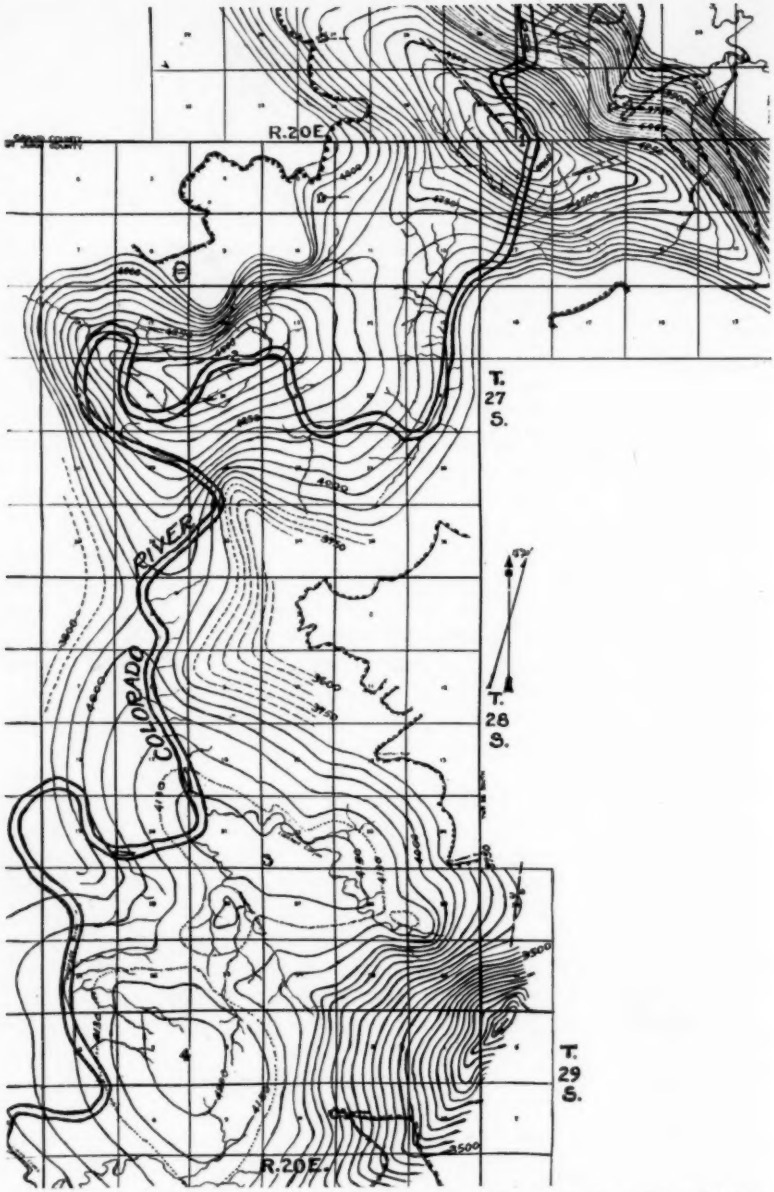


FIG. 10.—Structure contour map of (1) Cane Creek anticline, (2) Shafer anticline, (3) Lockhart anticline, (4) Indian Creek anticline, situated along the Colorado River, southwest of Moab, Utah (San Juan and Grand counties). The section lines on this map are projected from the northwest corner of Sec. 1, T. 26 S., R. 21 E. established by the U. S. land survey. Geological survey made May-July, 1921, by H. W. C. Prommel and H. E. Crum, geologists; A. J. Hazelwood and E. E. Johnson, instrument and rod, under the direction of Fisher and Lowrie. Structure contours drawn on top of Shafer limestone; contour interval, 50 feet; datum plane, sea-level.

Explanation

Contour and elevation
Closing contour
Approximate contour
Vermillion Cliff escarpment

Scale

of this region by the Colorado and its tributaries began. Their origin is of comparatively recent date. As the river cuts its way downward, the high rising walls, now towering 1,500 feet or more above the bed, pressing on the salt, have caused—it may be, are causing—the strata along the meander to bulge.

When in the preliminary paper read at the Dallas meeting of this Association (1926) the writer suggested this genesis for the Cane Creek Dome, there was much less substantiating evidence than now. Oil had been encountered at 2,028 feet, about 500 feet below the top of the salt. Theoretically, then, since the dome had 750 feet of closure, it should have had a minimum of 750 feet of salt displacement; hence the oil was in the midst of the salt mass. As stated, subsequent drilling has shown more than 3,000 feet of salt. The fold then probably originated

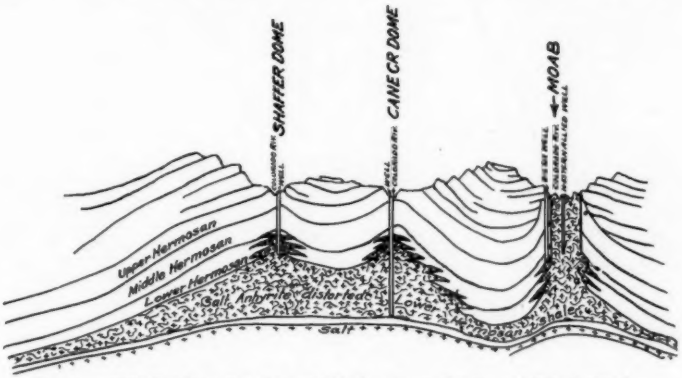


FIG. 11.—Idealized section through Shafer, Cane Creek, and Moab, Utah

in Pre-Pennsylvanian time. The salt moved into the anticline perhaps during the period within which elsewhere the plugs were being formed. Here, however, the salt movement was not so profound; the beds were not subjected to erosion and a fairly normal series exists. The relatively small amount of local doming is fully absorbed in the salt body. This dome, then, and the others associated are clearly the result of local adjustment within the salt mass (Fig. 11).

It should be understood that the writer believes that beds below the salt body at Cane Creek and Shafer are gently arched (Fig. 11), since it is supposed that these beds were folded before the early salt activity; but that these lower beds are also domed immediately below the salt is a very remote possibility.

MEANDER ANTICLINE

In the earlier paper, based on this premise, the writer stated that he ventured to predict that many other domes of peculiar distortion would be found within the salt region farther south along the deep canyons of the Colorado, Green, and their tributaries. During the discussion which followed, Harry A. Aurand an-

nounced that below the mouths of Indian Creek along the Colorado River meander the river bed itself for at least 16 miles had been folded and that this condition extended beyond the junction with Green River and into Cataract Canyon below. Since the meeting the writer has visited this part of the river.

Above the mouth of Green River the folding is, with one exception, confined to the meander. There it passes from the river bed through the walls of a narrow double oxbow. The walls in the bow are comparatively low. It is suggested that the great weight of the higher walls beyond controlled the salt flow. The fact should be stressed that within this locality from Indian Creek to the mouth of

FIG. 12.—Meander anticline 2 miles below Indian Creek. Upper Hermosan at surface along Colorado River standing at high angle. High scarps on each side are flat.

Green River, and for some distance beyond, the folding is confined to the beds immediately adjacent to the river. The high walls show no movement; they lie practically flat. At Indian Creek the Rico beds are in part exposed at the river level; the folding is gentle. The dip away from the stream is about 6°. A mile downstream, the Upper Hermosan appears (Fig. 12); the steep attitude has increased. Five miles farther, with 100 feet of Hermosan at the surface, the dip has reached 20°. At Cataract Canyon the river has cut its way several hundred feet into the Hermosan. There, the writer is informed, the movement has been intense and irregular. It involves a strip from a half-mile to a mile and a half on each side back from the canyon. The deep tributary canyons also contain folds.[1] The differential weight of the canyon walls in effect increases as the streams approach in their cutting of the salt beds. The amount of movement registered in the rocks should be greater here than farther up the river.

[1] Harry A. Aurand and B. H. Parker, personal communication.

The strong Cane Creek and Shafer domes have Upper Hermosan beds exposed at their crests, while the gentler structures of Lockhart, Indian Creek, and the Meander folding near the mouth of Indian Creek have Rico at the surface. It seems apparent that although, with the present loading, salt flowage will start when stream cutting has reached a point above the Rico, it becomes more active when cutting is proceeding within the Hermosan. The Meander Anticline is possibly now growing. Mr. Prommel, in a paper[1] read before the Western States Convention of the Western Division of the American Mining Congress, American Institute of Mining and Metallurgical Engineers, American Association of Petroleum Geologists, and American Silver Producers Association, held in Denver, September 20–24, 1926, described a large gypsum mass in Cataract Canyon. The accumulation had apparently reached its present position, in the bottom of the canyon, in comparatively recent time. Figure 13 illustrates the writer's conception

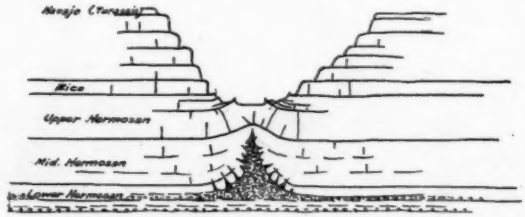


FIG. 13.—Illustrative section across Colorado River below Indian Creek

of the process by which the Meander Anticline was formed. That gypsum should locally reach the surface is incidental and to be expected.

The premise assumed by the writer is somewhat new. He therefore is justified in here calling attention to some analogous circumstances.

At Culebra Cut, in Panama, a gash of about 600 feet was cut for the canal. The high rising hills on each side pressing downward found relief within the canal itself. As the hills settled, the bottom of the canal rose. The movement has been largely stopped by lessening the load, cutting down the hills. Coal engineers are familiar with the principle in the pillar-and-room system of mining. Pillars are left to support the roof. The weight on these of the superincumbent strata very often caused the floor to buckle, frequently without warning and with a noise like the crack of a gun. An accumulated stress is certainly suggested.

The metalliferous engineer is familiar with the buckling which often occurs in the floor of a drift. This is a not uncommon occurrence in mines of Leadville.[2]

GREEN RIVER AREA

Where Green River enters the Colorado the folding is confined to the latter. This suggests that the Colorado earlier in its cutting reached the critical depth

[1] H. W. C. Prommel and H. E. Crum, "Salt Domes of Permian and Pennsylvanian Age in Southeast Utah and Their Influence on Oil Accumulation." (Not yet published.)

[2] John Wellington Finch, personal communication.

and the available salt was started toward that meander. Green River above the junction flows in higher beds well above the Rico. Several gentle domes are reported. One discovered by Marland geologists, however, shows a remarkable and very unusual development. This is the Christmas Canyon Dome. The structure, as described by B. H. Parker, who also is the author of the map (Fig. 14), is apparently located in an old meander of Green River. Coconino, or some higher associated bed, occupies the sharp and highly distorted crest, and Wingate occupies the trough which closely and completely circumvents it. Here, as elsewhere, it may be that with the cutting of the stream relief was sought by the salt by movement along some highly developed jointing or fracture.

The anticline and dome of that name lie along Indian Creek. The meanders of the creek are closely spaced, and the anticline here, as at the double oxbow on Colorado River, passes through the loops. Rico beds are at the surface within the

FIG. 14.—Generalized cross-section, Christmas Canyon Dome, Grand County, Utah

HART DRAW, SAN JUAN COUNTY, UTAH

canyon, while all beds above the Coconino have been removed from the adjacent area. It is suggested that these higher beds which formerly existed beyond the meander probably furnished the load under which the salt flowed. The dome has about 250 feet of closure. A test is being drilled on this structure.

BEEF BASIN, SAN JUAN COUNTY, UTAH

This dome is largely located in T. 32 S., R. 18 and 19 E. Supai beds are exposed in the canyons and Coconino and Moenkopie are at the surface. The structure also is said to have 250 feet of closure. Adjacent to it on the southwest is a sink which the writer is informed covers several sections.

SINKS

Sinks are associated with much of the salt-doming. They are formed, in the judgment of the writer, by the settling of the beds into the space left by the salt. Referring to Prommel's map (Fig. 10), it will be seen that east of Lockhart and Indian Creek domes a "syncline" is shown. This is in fact a "sink." South of Salt Creek Dome along the axis of the anticline is a sink covering fully three sections. On the Paradox fold (Plate 2) two sinks are shown, one between Dry Creek and Coke Oven, and one to the northwest just beyond Dolores River.

The domes and folds then of Groups III and IV are not associated with regional anticlines. Theirs is a growth due only to the differential provided by stream-cutting (Fig. 13). This being the case, only the beds above the salt should be involved in the folding. The beds below the moving salt should be practically flat.

THE LA SALLE MOUNTAINS

It is interesting to know that igneous intrusive rocks of very considerable importance are closely associated with the saline anticlines (Fig. 15). The laccolithic La Salle Mountains occupy an area on and between two parallel anticlines, Paradox-Castle Valley-Salt Valley and the Gypsum Valley-Lisbon Valley–Moab. A small isolated igneous stock surrounded by gypsum occurs in the Castle Valley salt plug (Fig. 15). The stock is fully 3 miles northwest from the laccolith proper. Butler[1] says,

> The age of the laccolith cannot be fixed definitely. The Mancos shale is involved in the doming so that the intrusion is later than Early Cretaceous. Cross places it as Tertiary based on an estimate of the time required for the erosion of several thousand feet of sediments that hypothetically must have overlain those now exposed at the time of the intrusion to account for the uniform conditions of cooling shown by the porphyries of the several laccolithic groups through a vertical range.

So much for the age.

Earlier in the paper the writer suggested that "the principles involved in salt flowage are similar to those underlying great diastrophic mountain-building movements and igneous activity." It has been stated that these anticlines are thought to have been lines of weakness since Precambrian time, that subsequently in Pre-Shinarump time they became saline anticlines and plugs were developed locally on them. There followed a very long period of subsidence, gentle during Triassic and La Plata, but more rapid during the Cretaceous; several thousand feet of sediments were deposited over the whole. It is suggested that the rapid subsidence of the heavy load generated heat which liquefied rocks within the zone of fracture, resulting in the flow which formed the laccolith, and the Castle Valley stock. Small sills are also reported by Coffin[2] in T. 43 N., R. 16 W., San Miguel County, Colorado. These are associated with the Gypsum Valley Anticline.

OIL POSSIBILITIES

Gulf Coast salt domes have produced from lateral beds, in many places inclined at high angles, and from beds above the plug itself.

In the opinion of the writer the salt domes of the Colorado Plateau offer evident oil possibilities. They deserve careful study and test.

In connection with the discussion of the Salt Creek Dome, mention was made of a favorable test made of bituminous fragments selected from exposed rocks, supposedly of Lower Hermosan origin, associated with the gypsum mass; also of

[1] B. S. Butler, "Reconnaissance Geology of Utah," *U. S. Geol. Survey Prof. Paper No. 111.*

[2] *Colorado State Bull. No. 16.*

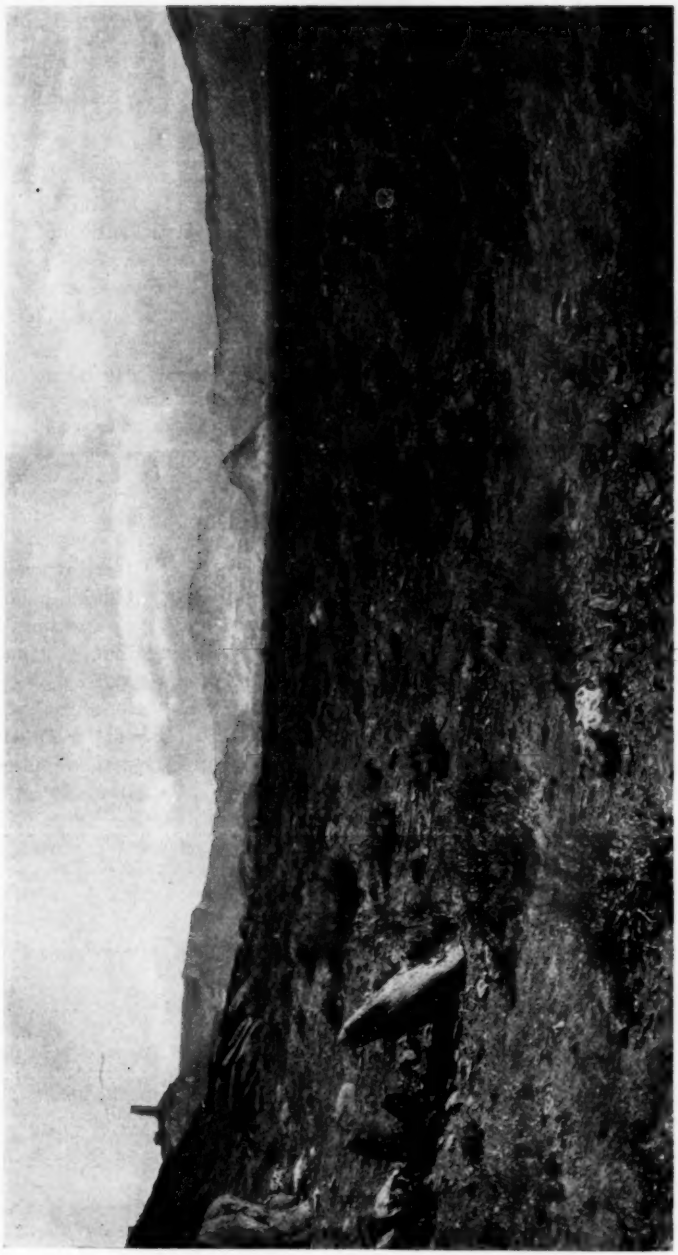


FIG. 15.—Castle Valley (looking southeast). La Salle Mountains in the distance. The igneous stock (the round truncated cone) is within the salt plug 3 miles northwest of laccolith proper.

hydrocarbon float formed in the detritus along the creek. Showings amounting to a total of several barrels of high-grade paraffin-base oil were reported from Paradox tests, and doubtless several hundred barrels came from the 2,028-foot discovery at Cane Creek. Showings of oil were also reported from the Western Allied and Big Six tests at Moab, and from the Crescent Eagle of Salt Valley. All these, in the judgment of the author, had origin in the petroliferous Lower Hermosan or older rocks.

At San Juan, in the extreme southeastern part of Utah (Fig. 1), oil has been developed in several wells from Upper Hermosan, there called "Goodrich." The oil has been developed in small quantities, and the structural situation is not particularly favorable.[1]

The fact remains that the Upper Hermosan is petroliferous.

West of Elk Ridge in the Colorado River canyon walls several hundred feet of possible Cutler sands are reported to be oil saturated. To a small extent oil is produced from the Moenkopie in southwestern Utah.[2]

Both the McElmo well, Sec. 23, T. 36 N., R. 18 W., Montezuma County, Colorado, and the Boundary Butte (unsurveyed), southeast Utah (Fig. 1), reported substantial showings of oil from the vicinity of the Shinarump horizon. The La Plata is also not without possibilities.

The Cane Creek well, now drilling below 4,600 feet (still in salt), will be carried down as far as practicable. It is also planned to attempt the test of beds below the salt plug with wells being drilled along the Paradox Anticline. In the opinion of the writer these tests are justified by the conditions. Only by drilling may the depth of the salt in a plug be determined, though it is believed that the base of it exists within the Lower Hermosan series. The beds below the salt within the regional anticlines are believed to be folded; and very possibly local doming exists in those beds, but only by prospecting with the drill will such domes be located.

At Paradox several wells are being drilled at intervals along the anticline. This plan is doubtless an advisable one. The depth of salt in the plug may not be known as yet, however.

The origin of the oil discovered at Cane Creek within the salt is an interesting problem which with our present knowledge is impossible of determination. It may have accumulated originally below the salt mass or in beds at the flank cut by the salt and thence migrated to its position within the salt, or the oil may have been generated locally from petroliferous shales and limes picked up by the flowing salt. All these are possibilities. It is doubtful that oil accumulated within a salt mass can, with our present known methods, be successfully produced. It is possible that a test of Lower Hermosan beds above the salt and on the steeper northeastern flank of the anticline is justified.

[1] Herbert E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper No. 93;* E. J. Woodruff, "Geology of the San Juan Oil Field, Utah," *U. S. Geol. Survey Bull. 471.*

[2] Harvey Bassler and John B. Reeside, Jr., "Oil Prospects in Washington County, Utah," *U. S. Geol. Survey Bull. No. 726.*

Possibly valuable pools of oil exist in steeply dipping beds on the flanks of the salt plugs (Group I). The Big Six well at Moab appears to occupy such a position. Several oil showings were reported. The lack of sand within the Lower Hermosan is an unfavorable feature. Either that well or one similarly located should be carried deeper.

A large number of the Group III structures should be tested. Domed strata above the moving salt offers promising possibilities of finding oil. Such tests will not exhaust the possibilities until the moving salt body, which will probably not be encountered under most conditions short of the Lower Hermosan, has been reached. To repeat, in this group, beds below the moving salt should be flat. Tests below the salt body, then, are not justified. Lockhart, Indian Creek, Hart Draw, Beef Basin, all have Rico beds at surface, and thus should be tested for Upper and Middle Hermosan, and also for beds above the moving salt of the Lower Hermosan. Dove Creek and Dolores are large, gentle folds, perhaps too large, that may justify tests of horizons above the Hermosan. The main criticism one may offer for all these structures is that the folds are very large, with broad crests and relatively small closure.

The Christmas Canyon Dome in the Green River area is at the other extreme; the beds have been too highly buckled and faulted. In this region, however, several gentle domes involving the higher beds have been reported. Possibly some of these will justify tests.

The Dry Creek Dome warrants further test; the Gilmore well should be carried deeper. If the writer is correct in his diagnosis that the Red Bed series overlaps the salt plug as a blanket, secondary oil may have accumulated in these beds. C. B. Osborne recently informed the writer that some very encouraging showings of oil and gas were encountered toward the bottom of the well, now at 2,700 feet.

The writer is not now prepared to suggest any part of the Meander Anticline for test, though with further knowledge on the subject local doming on it may warrant attention.

CONCLUSION

Briefly, then, saline structures of different character and genesis exist in the Colorado-Utah high plateau region. The writer believes that the principles of isostasy have governed the development of those structures—differential loading furnished the stress, and some external movement the impulse. The weight of superincumbent strata within the basin or trough resting upon the bedded strata of salt and anhydrite has caused—it may be, is causing—these to flow as a plastic mass into the adjacent anticline or other area of relief.

Primarily saline structures are of two varieties: those that have reached the plug stage, and simple domes. For purposes of discussion they have been placed in four groups.

Group I dealt with saline anticlines on which plugs have locally developed while to Group II was assigned a similar anticline on which domes had locally developed. Groups III and IV dealt with structures believed not to be associated with anticlines.

It is believed that the anticlines which parallel each other are on lines of weakness which originated in Precambrian time and that successive cycles of earth movements have accentuated the folds and at the same time deepened the basins. The evidence shows that prior to Shinarump deposition the salt flowed into these structures and in many places reached the surface in the form of plugs.

At Cane Creek and Shafer domes, however, though salt moved into the anticline at this early time, it did not reach the surface. The two local domes probably owe their existence to the differential load created by the high walls rising on each side of the cutting stream. These resting on the salt have caused it to flow toward the area of relief, the river canyon itself. The comparatively small amount of doming—750 feet of closure in one and 500 in the other—has been absorbed in the great body of salt, now known to exceed in thickness 3,000 feet.

The writer has also dealt with the other groups, those structures not associated with anticlines and the Meander Anticline of the Colorado River. These, as in the case of Cane Creek and Shafer, have, he believes, a recent origin due to the differential loading built up by the cutting stream. The evidence developed by the drilling well at Cane Creek; the fact that in practically every case the crest of the structure is deeply cut by a stream; and the conditions surrounding that remarkable development, the Meander Anticline—these factors, reviewed as a whole, have led the writer to his conclusions.

Finally, the oil possibilities have been reviewed; a large series of strata are petroliferous. Here, as in the Gulf Coast, however, proper location for testing is most difficult of determination. In addition to wells being drilled on the crest at Cane Creek and at Paradox, a test of beds above the salt on the northeast flank of the structure is suggested for Cane Creek. It is believed that strata above the salt mass on the simple dome should also be tested. Such tests are being drilled at Hart Draw and at Dry Creek. Study should also be given with a view to testing the flanking beds of one or more plugs.

The writer is of the opinion that with increasing knowledge of the conditions surrounding this salt-dome region, it is quite within the realm of possibility that valuable oil will be developed. Careful study and thorough tests are warranted.

GEOLOGY AND THE PETROLEUM AND NATURAL GAS POSSIBILITIES OF PALESTINE AND SINAITIC PENINSULA[1]

F. JULIUS FOHS[2]
New York City

ABSTRACT

The presence of asphalt and oil showings in the vicinity of the Dead Sea and near Hasbeya, west of Mount Hermon, has long been known; and these, together with the asphalt-rock occurrences, have led many to believe commercial oil deposits might be found in Palestine. The so-called asphalt rock or bituminous limestone has no relationship to the occurrence of oil. The asphalt and oil seepages, where present along fault lines, signify nothing as regards commercial oil where they appear, except as they are suggestive that, in localities where traps occur which have not been disturbed by faulting, oil may be present in commercial quantity. Although all of Palestine is faulted into large fault blocks, within such blocks there are thirty-seven structural domes which might act as traps for oil and gas; but where igneous intrusions occur with such structures, it is less likely that they will produce. Promising domes occur in Palestine west of the Jordan and the Dead Sea, with the possible exception of the basalt-covered areas. From the Jordan and the Dead Sea eastward to the Hedjaz Railway, because of the basalt intrusions and exposure of lower beds by uplift, there is very little promise, though some folds are probable in this area. Of a total of 12,700 square miles in Palestine proper, more than 300 square miles offer structural conditions warranting tests for oil and gas. This offers an unusually high percentage of possible oil-bearing area, considering the small size of the state—about the size of Vermont.

The Sinaitic Peninsula also offers possibilities.

The formations range from Eocene to Precambrian. Cretaceous limestones and marls form the great bulk of the beds to be penetrated, and next below is the Nubian sandstone and several hundred feet of Carboniferous sandstones, limestones, and shales. There are eight possible oil horizons, half of which have a good chance to produce.

With ample reservoir beds, with ample source material, and with good structural traps, we see every reason for the development of an oil supply in Palestine. We are anxious to see this development undertaken because it would speed the upbuilding of Palestine as nothing else can.

STRATIGRAPHY

Table I gives the general stratigraphic section. A summary of possible oil-gas horizons is given later, and the map (Fig. 1) shows their areal distribution.

STRUCTURE

The structure of Palestine is extremely complicated, though it can be grouped around certain larger structural features, of which the most important, perhaps, are what may be called the "Jerusalem geanticline," a large earth arch where the strata are uplifted, and the "Ghor fault block," where, on the contrary, a block of the strata is depressed and forms a typical trough-valley. This is part of one of the greatest trough-valleys known, extending from Mount Hermon, south to Nyassaland, more than 3,000 miles. A typical cross-section in Palestine is shown in Figure 2.

[1] Paper read before the Association, at the New York meeting, November 16, 1926.

[2] Consulting oil geologist, 51 East 42d Street, New York, N.Y.

TABLE I

GENERALIZED STRATIGRAPHIC SECTION OF PALESTINE

(After Blanckenhorn, Hull, and Hume)

				Feet
Recent	Alluvium			20
Quaternary	Diluvium		Upper Middle Lower	0–200
Miocene	Exposed in Sinai and to small extent on Sinaitic plain			
Eocene (basalt eruptives in this period)	Calcareous sandstone of Philistia		Porous, bedded, uniform. Resembles dolomite. Occurs Philistian plain only	0–50
	Upper		Yellow to white nummulitic limestone, cherty, marble-like, part dolomitic, with free nummulites, partly nummulitic sandstone	500
	Lower		*Alveolina* and orbitoidal limestone (in Sinai)	1,320
	Senonian (Neocretaceous) 800 ft. characterized by dark flint bands	Danian	2. Varicolored gypseous marls with thin layers and veins of gypsum and limestone. Estimated thickness	200
			1. Asphaltic, coprolitic, phosphatic limestone or green marble (east of Jordan, total Danian 528 ft.)	225
		Campanian 1,150 ft. in Sinai	2. Bituminous and chalky limestone, bituminous marl and flints	750
			1. Yellow, white chalky limestone (100 ft. Sinai Peninsula including Danian)	
		Santonian	Upper ammonite horizon. Chalky limestone in (Sinai, 330 ft.)	0–82
Upper Cretaceous (basalt eruptives in this period)	Turonian (330 ft. in Sinai, 700 ft. in SW. Judea)	Basalt at Mount Carmel Basaltic limestone bed	Nerinee marble (Mizzi helwi), laminated limestone, concretionary limestone with large melon-like chalcedony concretions and druses (Jerusalem, 140 ft.)	90–700
Upper Cretaceous (Mesocretaceous)	Cenomanian (Sinai 660 ft.)		3. Thick green-gray marls interbedded with limes containing echinoderms; fossil type localities Ain Homer and Wadi Mojib	250
			2. White, yellow, and brown limestone with orbitoids, and small ammonites	1,100
	Albian ? absent		1. Yellow fossiliferous marls	300

TABLE I (*Continued*)

			Feet
Lower Cretaceous	Nubian sandstone (Neocenomanian, Petra, or Monumental)	Upper half of so-called "Nubian" sandstone (1,000 ft. exposed east of Jordan and Dead Sea)	600–1,500
Unconformity	Transition beds	Lime gravels, quartzite beds, and marl beds (many resting on Cambrian dolomite)	
Jurassic (absent except at Mount Hermon)	Upper Glendarian limestone	Absent at Hermon (in Lebanon)	
	Lower Glendarian limestone	Limestone and splintered chalk with *Rhynchonella moravica* and *Cidaris glendaria*	
	Clayey limestone	With *Pecten capricornus*	
	Yellow-gray chalky marl	With *Collyrites bicordata*	
	Blue-gray clayey lime slates	With *Harpoceras socina*	
Unconformity	Between Nubian and Carboniferous sandstone	Sandstone	225
		Shale beds	150
		Sandstone (425–95 ft. in Sinai)	100
		Dark gray limestone weathers brown with crinoid stems, corals, and brachiopods (iron and manganese ores at base in Sinai)	20–130
Upper Carboniferous	Wadi Nasb limestone		
Lower Carboniferous Unconformity	Desert sandstone (Lower Nubian)	Sandstone with *Sigillaria* and *Lepidodendra*	150–430
	Dolomitic limestone (probably Cambrian)		150–180
Cambrian	Red and green-gray marls		42
	Massive red sandstone		720
Unconformity			
Precambrian (Algonkian)	Semistratified, semivolcanic beds; bright-colored arkose, partly conglomeratic with large boulders of granite; porphyry and felsite dikes		
Unconformity			
Archaean	Older eruptives; porphyry and porphyrites, diorites, diabase, red, white and hornblende granites; crystalline schists		

On either side of the geanticline, synclinal trough-like fault blocks appear; and the coastal block, capped with younger formations, is depressed. Immediately east of the Ghor fault block, on the east side of the Dead Sea, the formations generally are uplifted; a west-northwest axis passing through Bethlehem would be along the line of greatest uplift while the geanticline and other formations drop southward and northward from this cross axis; to the northward the geanticline, eastward of Mount Tabor, is greatly depressed and basalt covers its extension in

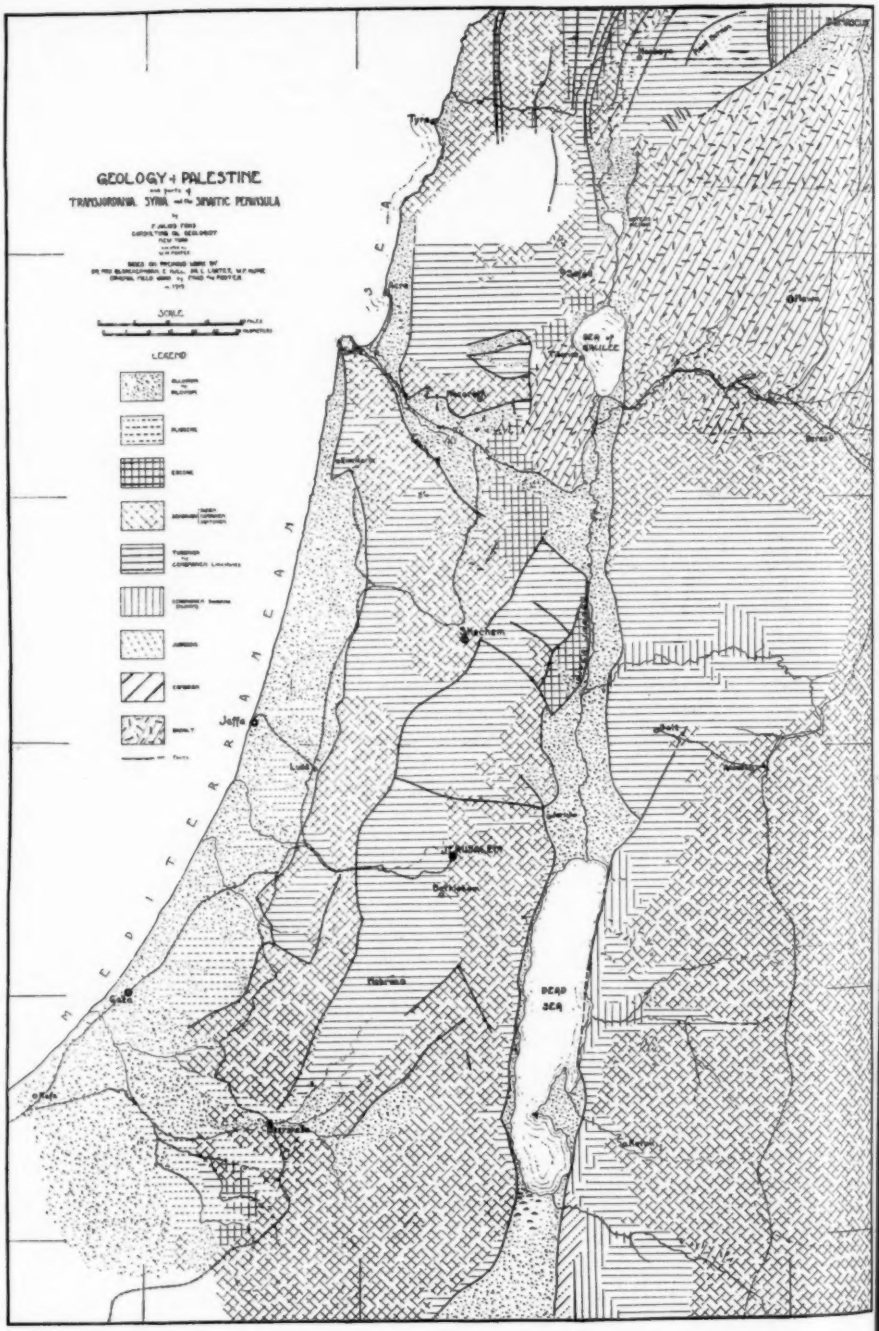

GEOLOGY of PALESTINE
SCALE
LEGEND
MEDITERRANEAN SEA
Tyre
Acre
Haifa
Jaffa
Lydda
Jerusalem
Bethlehem
Hebron
Gaza
Beersheba
DEAD SEA
Jericho
Nazareth
Tiberias
Beisan

FIG. 1

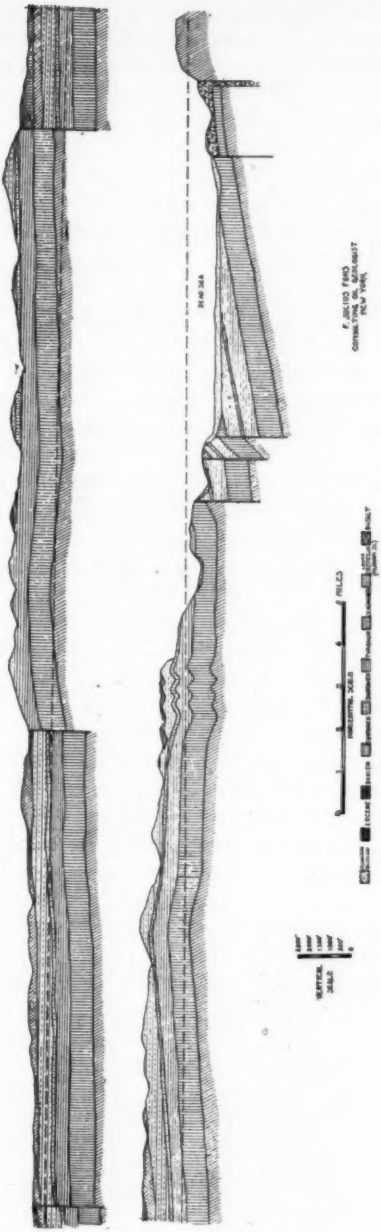


FIG. 2.—Typical east-west section in Palestine

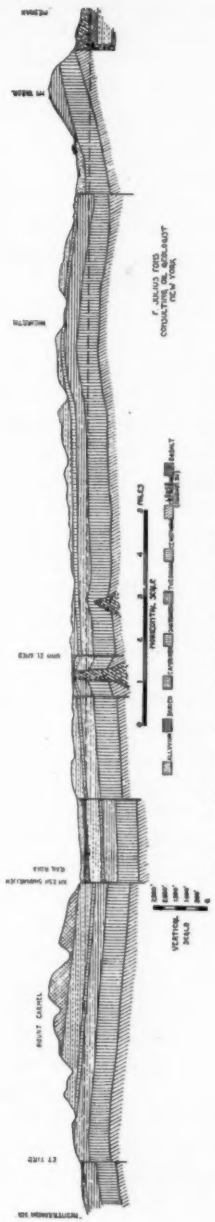


FIG. 3.—Section through Et Tire, Nazareth, and Mount Tabor

this area. To the northwest of Saifed a mild expansion of the fault appears. Occupying and paralleling the valley of the Esdraelon is a depressed fault block extending from Haifa to the Jordan in a southeast direction. This area is occupied with several basalt intrusions.

The Ghor is a narrow depressed fault block extending from the Gulf of Akaba, along Wadi El Araba, the Dead Sea, the Jordan Valley, Lake Tiberias, Lake Merom, and thence northward, splitting into several fault blocks north of Lake Merom but maintaining its main course west of Mount Hermon along Jobel and Dohr and Nahr el Litani. Northward of Lake Merom the structure becomes very much more complicated and consists of a series of faults with alternate uplifted and depressed blocks.

The strata of the Ghor block probably dip westward with a secondary fault zone on either edge. A typical section is herewith exhibited (Fig. 3). The surface beds are, for the most part, alluvium and diluvium except that northward, just south of Lake Tiberias, basalt intrusions appear; and still farther northward these continue to a greater extent along the block until north of Lake Merom, where Eocene and Senonian beds, Cenomanian and Nubian sandstone, in alternate strips, constitute this block; and still farther north, in the vicinity of Nahr el Litani, diluvium beds occupy part of it. This block is from 5 to 15 kilometers wide. The surface elevations south of Lake Tiberias range from 450 to 1,292 feet below sea-level. It is part desert, with some oases where fresh-water springs appear as at Ain Jidi.

The general strike of the several fault blocks of Palestine parallels the sea coast, which has a general direction of N. 21° 30′ E., with a series of cross-faults approximating N. 48° W. The area may be divided, for further description, into these several fault blocks, considering first those south and later those north of the Esdraelon block.

The Jerusalem geanticline is a large uplifted fault block, the apex of which is southwest of Jerusalem, just north of Deir esch Sheikh south of Saris. In a general way this block drops rapidly to the south toward the region just east of Beersheba and more gradually northward toward the region 5 miles east of Nablus, with a series of fault blocks still farther northeast. It constitutes what are known as the Judean Hills, with an altitude ranging from 1,500 to 2,900 feet. The surface beds are, for the most part, Cenomanian limestone. This area is practically devoid of soils, with the exception of minor terracings and wadi bottoms. It is notable that the Arabs use the hilltops for their villages, partly because of better climatic conditions—the nights always being cool and a breeze present through most of the hottest summer days.

Immediately west is what may be termed the Beit Jibrin-Nablus block, forming, for the most part, a trough-valley block, with Mount Carmel as its northwestern extension. North of Jenin are several minor basalt intrusions. In this area the elevations are lower, ranging from 400 to 1,800 feet. The surface beds are Senonian and, to a less extent, Cenomanian. Part of this block is semidesert.

Farther west is what may be termed the Philistia block, which has a surfacing of alluvium, diluvium, and some Eocene beds. This block borders the Mediterranean coast and, except for the alluvial sand patches, is the largest and best agricultural area in Palestine. It extends from south Zimarin, past Jaffa and Lud, to Gaza, Rafa, and El Arish.

West of the geanticline is what may be termed the Khan Hartrura-Kornub trough-valley block, the surface beds of which are primarily Campanian, especially upper Campanian, and include more Danian than elsewhere in Western Palestine. Northeast of Jerusalem, in the deeper valleys, Cenomanian beds are exposed; and still farther north, just east of the Jordan, some Eocene blocks appear. The surface elevations range from 200 to 2,300 feet. This area ranges from desert to semidesert.

The Esdraelon block is a depressed synclinal block along the borders and in the interior of which basalt eruptives occur. This block has a low altitude, ranging from 175 to 400 feet. It is bounded on the east by depressed, but higher, blocks of Eocene, Senonian, or basalt rocks.

Structure, as previously indicated, is of prime importance to the occurrence of the principal promising resources. Thus petroleum and natural gas are to be sought on the structural domes, and in a territory like this, having a major amount of rigid (limestone) beds with marked faulting, the badly faulted localities are to be avoided; also, since the beds probably contain much salt water, the synclines are unfavorable for these products. The principal asphaltic limestone occurrences are known only in the major synclinal areas. Some asphalt breccias appear along the faults.

The many small springs of Palestine are directly related to the structural domes, the tilted beds near the crest of the domes—generally near the tops of hills or ridges—act as an intake source for the water, while lower, along the sides of the hills, the same beds outcrop and from them the water issues as springs. It would be possible, with the aid of the structural maps, to determine the approximate depth at which a given spring horizon could be tapped with a well, or whether such a well would be warranted.

OIL AND GAS POSSIBILITIES

OIL AND GAS HORIZONS

Table II shows the more important possible oil and gas horizons, and a study of this table, in conjunction with the stratigraphic table, will prove helpful.

DOME TYPES

We mapped thirty-seven localities that have greater or less possibilities for oil and gas, embracing the following types:

a) Domes of considerable area, with excellent closure and ample cover (shown in Locality No. 1, Fig. 4)

b) Small domes, with considerable depth of cover over important horizons; more promising for oil than for gas (shown in Localities No. 2 and No. 4, Fig. 4)

c) Probable dome, with Eocene beds at surface, and with possibilities in Danian beds

d) Large flat structures, promising for gas (shown in Locality No. 3, Fig. 4)

TABLE II

POSSIBLE OIL AND GAS HORIZONS

Formation	Maximum Depth (Feet)	Possibilities	Minimum Depth (Feet)	Possibilities
Danian (Upper / Lower)	300	Asphaltic limestone		
Campanian	650	300 ft. below top; possible chance gas; small gas; light oil		
Cenomanian	2,000	200 ft. below top; possible chance gas and light oil		
Nubian sandstone	3,000–3,500	Top best chance light oil and gas. 500 ft. below top good chance light oil	250–750	Heavy oil Medium oil
Upper Carboniferous sandstone	4,250–4,500	Good chance oil and gas	1,500–1,750	Good chance oil and gas
Wadi Nasb Limestone	4,750–5,000	? If always present possible chance light oil and gas	2,250–2,500	? If always present possible chance light oil and gas
Lower Carboniferous: Sandstone shale	? 5,450	Chance	?	Chance
Lower Carboniferous: Basal sandstone		Small chance	2,950	Small chance
Cambrian				
Precambrian		Useless to test		Useless to test
Granite		Useless to test		Useless to test

e) Large open-spread structures, with possible horizons, very shallow; hence chances best for small wells, low structurally, with low gravity oil

f) Areas in vicinity of basalt overflows

g) Half-domes against faults

The first four types should be tested first. It is to be hoped that the Government of Palestine will arrange for gradual development of the territory over a period of years. It would be a great economic waste to permit unrestricted develop-

ment of all oil-and gas-bearing areas at one time; and, in view of the sad experiences of America, Mexico, and other countries, it is hoped the Government of Palestine will, from the outset, adopt a wise policy of conservation.

Twenty-three domes of more or less promise, covering more than 1,000 square miles, were mapped in Western Palestine, with the probable position of four additional ones suggested, and several others were mapped which may be valueless

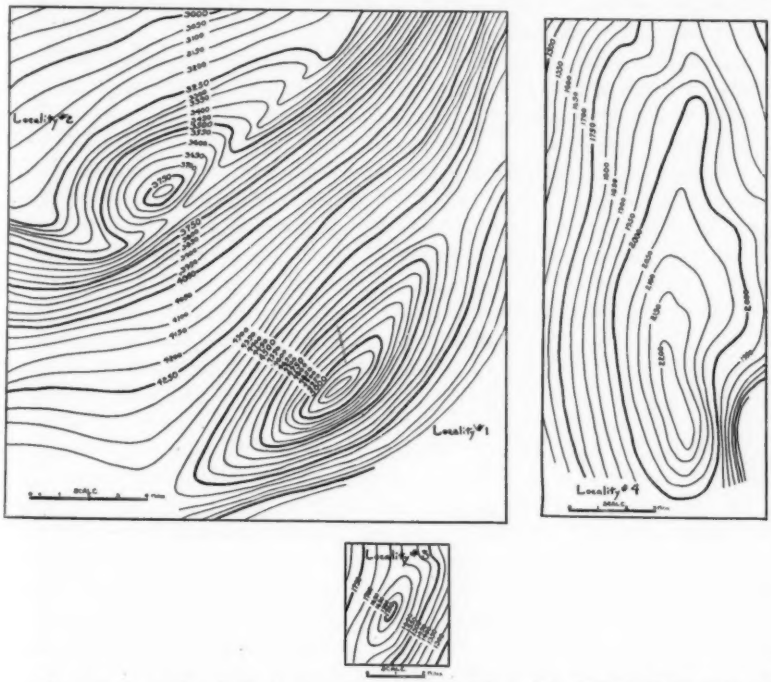


FIG. 4.—Types of geologic structures in Palestine. (Mapped by F. Julius Fohs, assisted by W. H. Foster.)

because of faulting or igneous intrusion—this out of a total area of almost 12,700 square miles. About 300 square miles are considered promising for oil and gas, of which 100 square miles (64,000 acres) are especially promising—a very high percentage for a small country. The surface land is, for the most part, valueless at present for agricultural purposes except in occasional wadi bottoms or small limited terraces; and a large part is actual desert or semidesert.

The largest of the domes is 32 miles long and 3½ miles wide, and the smallest covers only one-fourth of a square mile.

The character of the structural traps is, for the most part, very good except that the larger structures are less promising.

RESERVOIR BEDS AND SOURCE MATERIALS

Absence of thick shale covers and good reservoir sandstone lessens materially the number of chances for petroleum concentration. Nevertheless, several good reservoirs remain, notably, (1) the dolomitic limestone horizons, porous partly because of brecciation, concurrent with alteration from calcite to dolomite, involving shrinkage, and partly because of the shape of the dolomite particles; and (2) Nubian sandstones; and possibly (3) the Wadi Nasb limestone; and (4) the Lower Carboniferous sandstones.

Since there are several dolomite horizons and at least two sandstone horizons, and since our experience in the United States has taught us that many dolomitic reservoirs are highly productive, our concern is chiefly with the effectiveness of impermeable coverings.

It follows that the greatest questions concerning the concentration of petroleum here are whether the 250 to 300 feet of basal Cenomanian marls are thoroughly ample to prevent the escape of the oil, especially in the shallower structures, and whether these were ample to supply a large amount of oil to be later concentrated in the sandstone just below. The seepages of asphalt and oil spring occurrences previously noted suggest that some oil did occur, and this, together with the well-defined structural conditions, makes the prospects well worth development.

Aside from the larger marl covering just mentioned, smaller marl layers, ranging from 1 to 2 feet in thickness, occur between the lime (chalk) beds, throughout the Cenomanian formations.

Where Danian beds are at the surface, a considerable additional thickness of marls seals the limestone series below, though this last is true only in a few places, as, for example, in the Philistian plain and at Gebel Tanka in Sinai. The recent developments in west-central Texas answer a question I have long puzzled over—the occurrence of considerable amounts of oil where there is a great thickness of rigid beds with little in the way of bituminous or other shales interbedded. Aside from impermeable shale coverings, we have come to have a great respect for the efficiency of cap rocks created by the effective cementing of the uppermost 6 to 12 inches of the reservoir bed itself. Except, therefore, where faulting has caused excessive fracturing and especially where such fracturing has taken place after the accumulation of the oil, we conclude that there is ample impermeable cover to a number of reservoir beds in Palestine.

In connection with his discussion of the oil occurrence of Gebel Tanka, Hume expresses the opinion that the primary source of the oil is the Cenomanian marls, and in this I concur. He found outcrops in at least two localities in west-central Sinai of oil-bearing marls of at least a meter total thickness, from which he concludes:

> It appears from the above analytical results that the oil marls at their exposed faces contain on the average about 1.3 per cent of hydrocarbons, of which roughly three-quarters is oil and the remaining quarter is asphalt. The high proportion of asphalt to oil is indicative of inspissation at the exposed faces, and it is not unlikely that the oil content

may be larger further in the beds. But even if we reckon on only 1.3 per cent throughout, and an average thickness of a meter for the oil-bearing marl, we have a content of over 25,000 tons per square kilometer (247.1 acres). Thus, though the percentage of oil in the marls is far too small for them to be of any economic value as a direct source of oil, it is quite sufficient to provide sufficient quantities at points where natural conditions may have concentrated it.

These oil-bearing marls were located 360 feet above the Nubian sandstone. He further says:

> The occurrence of oil marls at Etler el Zur and Wadi el Nakheila appears to be independent of volcanic action as no intrusions of igneous rock were visible in their vicinity. . . . . They have the appearance of being primary deposits formed in the marls by the decomposition of native organisms.

In a thickness of 250 to 300 feet of Cenomanian marls, with only a few thin limestone layers interspersed, a goodly body of source material occurs aside from the specifically oil-bearing layers; and, though the percentage of organic matter may be very small, it still mounts into enormous figures when thickness and square miles of area are considered. Besides, great thicknesses of highly fossiliferous Cretaceous limestones occur; and, in addition, the Carboniferous shales interbedded with the Nubian and Lower Carboniferous sandstones and also the Wadi Nasb limestone are present as source material. Hence, with at least 400 feet of marls and shales, besides the fossiliferous limestones, we conclude that there is no lack of source material.

These marls are nowhere exposed in Palestine west of the Jordan and the Dead Sea, but do outcrop, due to an uplifted fault block, on the east shore of the Dead Sea.

The nearest developed oil fields are those of Egypt at Jebel Jensa and those near the southwest coast of Persia. Both of these fields are in Miocene beds and therefore bear no analogy to the Palestine possibilities, which are in Cretaceous beds. The nearest analogy is in the Algerian occurrences and these have not been developed to any degree, largely because of the prohibitive French laws.

With ample reservoir beds, with ample oil source materials, and with good structural traps, we see every reason for the development of an oil supply in Palestine.

Transjordania.—This area offers slight or no oil possibilities, although there are oil seepages, since the beds are largely exposed by faulting and by drainage.

Sinaitic Peninsula.—This offers several domes of the same type as those mapped by us in Palestine—in part mappable, in part covered by recent sands and diluvium. In addition to basalt eruptives, such as occur in Palestine, it also has some older granitic rocks in the vicinity of Mount Sinai.

Hume states that, in the vicinity of the Red Sea and parallel to it, some oil possibilities occur. Some test wells were drilled at Gebel Tanka, and from one of these oil flowed when a depth of 1,151 feet was reached, and, while the well was never brought to the production stage, it stood full of oil when seen by him—oil

of an asphalt base and a gravity of 0.955. This oil is thought to have come from Eocene limestone at a depth of 285–366 feet. Other showings were as follows: asphalt and oil indications from 2,024 to 2,062 feet; gas in the Cenomanian marls at 2,281 feet; and black sand and water at 2,340 feet, as well as oil indications at 2850–55 feet, in Nubian sandstone. Just what the character of the structure is here we do not know, although Hume believes there is faulting, but the presence of the shallow oil clearly indicates that the deeper horizons were not tested sufficiently high on structure for an effective test.

SUGGESTIONS AS TO DEVELOPMENT

Owing to lack of test wells for comparison in Palestine and lack of knowledge as to water saturation conditions in promising sands, it may take three or four test wells on each of the larger structures to determine the position of the oil, if any is present. It is probable, however, that oil in the shallow sands will be found on much lower structural contours than that in the deep sands. Should the more northerly structures produce, owing to proximity to igneous intrusions, gas or heavy (fuel) oil only may occur, though elsewhere (except where sands are very shallow, that is, have slight depth of cover) structures may yield light, higher-grade oil as well as gas.

The surface beds range from basal Cenomanian to Eocene and the maximum depth of tests recommended ranges from 1,900 to 5,200 feet. Such tests cost, in America, from $20,000 to $90,000 each. In Palestine, the freights and other increased costs would probably increase this materially (possibly 50 to 100 per cent), as, for a time, it may be necessary to transport both material and skilled labor from the United States for these purposes, though other steel-producing countries might furnish casing and other supplies more cheaply.

It will probably be necessary to import skilled labor for drilling the wells. Working hours should be so arranged, especially during the hot season, that no work need be done between 10:30 A.M. and 3:30 P.M., when the heat is greatest; and, as is usual in American oil fields, day and night shifts should be provided.

Owing to the hard drilling to be expected because of the thick limestones to be penetrated, standard tools, with heavy bits, should be employed for all but the shallowest drilling, though rotary tools may be necessary for the first few hundred feet in the plains of Sharon and Philistia and a combination rig will probably be most serviceable for the deep tests. For drilling tests shallower than 2,000 feet, the large Star No. 23 or National No. 2 portable drilling rigs may be used. First-class drillers are necessary to develop properties of this type successfully. For tests to a depth of 2,500 feet, light-weight casing may be employed. For deeper tests, extra-heavy casing is recommended.

ASPHALT ROCK

The following types of occurrence of asphalt and asphalt rock have been found in Palestine: (1) masses or blocks rising on the surface of the Dead Sea, (2) asphalt filling fissures and as dolomite breccia cement, (3) asphalt impregnating sandstone and from springs, and (4) asphaltic limestone in beds in the basal Danian.

These deposits are of little or no interest from the standpoint of a direct relation to commercial oil occurrences, though they do partly indicate some oil accumulations in the beds with which they are associated, and thus indirectly justify testing localities where suitable traps occur undisturbed. With one exception, testing is not warranted, however, in the vicinity of the asphalt occurrences. These deposits are of interest, nevertheless, because of their own value; that is, the second and fourth types may locally be valuable, the fourth being the most important.

The asphaltic limestones, the most important of the asphalt rocks in Palestine, are found at Neby Musa, Khan Hartrura, in the Buekia, in Wadi Yarmuk by El Hamma and Mukes, in El Arab and Jabbok wadies, between Ziza and Deraa station on the Nedjaz Railway, and at several other places, some of which are shown on the structural maps. These limestones are primarily confined to the basal beds of the Danian and occur commonly in the synclinal depressions, interbedded in many places with the phosphate rock beds and bituminous shales. They have a thickness ranging from 1 to 7 feet and are in layers from 10 to 14 inches thick. Analyses show that these asphaltic beds contain from 13 to 25 per cent of bitumen. The bitumen marls contain only a small percentage of bitumen.

The probabilities are that this bitumen originated with the lime as laid down and was not later infiltrated unless partly from immediately adjacent shales; that is, these occurrences have no relation to oil pools, nor are they indicative of such pools. The layers at Neby Musa occur through beds 60 feet thick; the best limestone, however, is in a thickness of 15 feet.

Of asphalt in fissures or cementing breccia, there are two notable occurrences: one in the Hasbeya, near the foot of Mount Hermon, where some asphalt was dug for several years, and another in Wadi Muhauwat. This deposit is near the northwest edge of Djebel Usdom. Blanckenhorn estimates the cubic content of the breccia or conglomerate at this point at about 20,000 cubic meters with a minimum of 18 per cent asphalt content, equivalent to 4,000 cubic meters of asphalt or 4,000,000 kilograms, based on the specific gravity of 1.1. This asphalt could be readily extracted by heating, leaving behind the hard conglomerated or brecciated matter.

On the east of the Jordan, in Wadi Sabbeh, Blanckenhorn describes a vertical exposure, with a height of 90 meters, from the lower part of which asphalt drips. It is in the vicinity of a fault which borders the Jordan depression. Siliceous dolomite, with cavities filled with asphalt, is seen at the foot of the exposure, while the asphalt occurs in stalactitic masses in larger openings in the wall above. This occurrence is 200 meters above the surface of the Dead Sea and three kilometers east.

In the southern two-thirds of the west coast of the Dead Sea, from Ras Merseb on, there are found in the lower part of the outcropping Turonian-Cenomanian beds of asphalt, impregnations probably infiltrating from below. The dolomite by Merseb and the limestone by Ras Merseb are thus impregnated, and the soft limemarls which appear on the sides and base of Wadi Umm Baghik are spotted brown and burn like the asphaltic lime of Neby Musa. These are all minor occurrences

and of little consequence, with the possible exception of that at Wadi Muhauwat.

The blocks or masses rising on the waters of the Dead Sea may originate either from fissures and faults in the floor of the sea or by agglomeration from asphalt washed into the sea from the nearby springs, faults, and breccia. They are of scientific interest only.

ACKNOWLEDGMENTS

This work was undertaken under the auspices of the Zionist Organization, with the approval of the British War Office, through whose auspices we were supplied with a guard of gendarmes by the O.E.T.A. of Palestine. Our full report was submitted both to the Zionist Organization and to the Palestine Mandatory, through the British Colonial Office. My acknowledgments are due the representatives of these organizations for their assistance.

To William H. Foster, who assisted me throughout the work, special thanks are due, and also to Professor Lewis E. Westgate, who acted as special investigator. May I also here acknowledge my indebtedness to those valiant investigators, French, German, and English—particularly to Lartet, Kitchener, Hull, Hume, and Blanckenhorn (Dr. Blanckenhorn did a large amount of excellent work)—whose work I used as a basis? In a select bibliography, hereto appended, I list the more important publications and maps.

Acknowledgment is also due to my interpreters, Messrs. Shertock and David Kahan.

SELECT BIBLIOGRAPHY

1. Bissinger, E. "Petroleum Discovery in Syria," *Rep. Cons. U. S.*, Vol. 33 (1890), pp. 210–12
2. Blanckenhorn, M. "Nutzbare Mineralien am Toten Meere," *S. pr. Geol.*, 1897, p. 360.
   ———. *Die Strubeturlinien Syriens & des Roten Meeres.* 1893.
   ———. "Über das Vorkommen von Phosphaten, Asphaltkalk, Asphalt und Petroleum in Palästina," *Z. pr. Geol.*, 1903, p. 294.
   ———. *Syrien, Arabien und Mesopotamien* (Carl Winters.) 1914.
3. British Admiralty. *Geology of Mesopotamia and Its Borderlands.* London, 1918. Pp. 110 with bibliog.
4. Buhl, F. *Geographie des alten Palästina.* Freiburg und Leipzig, 1896.
5. Burckhardt, J. L. *Travels in Syria and the Holy Land*, 4 vols. London, 1882.
6. Caillard, R. du. *Petroleum in Syria in the Fifteenth Century B.C.* Pp. 292. 1887.
7. Cumberbatch, H. A. "Bitumen and Asphalt Deposits in Syria and Palestine," *Board of Trade Journal*, Vol. 61 (1908), pp. 38, 39.
8. Delachanal, B. "Sur la Composition de l'asphalte ou bitume de Judée," *Compt. Rend.*, T. 97 (1883), pp. 491–94.
9. *Der Deutsche Palästina Verein.* (Maps of Eastern Palestine.)
10. Diener, C. Libanon, 1886.
11. Eastern Palestine—partial map East of Jordan; survey of works of Schumacher.
12. Elsner, C. "Die Asphalte und Bituminosen Kalke Palästinas," *Chem. Rev. Fett-Harz-Ind.*, Bd. 8 (1901), pp. 159, 160.

13. Fraas, O. *Aus dem Orient; Geologische Beobachtungen am Nil, auf der Sinai-Halbinsel und in Syrien.* 8 vols. Stuttgart, 1867.
14. Gaillardot, C. "Dead Sea Asphalt," *Ann. Soc. Emul. Vosges,* T. 6 (1849).
15. Galilee—final topographic map in U. S. Geological Survey Library.
16. *German Palestine Verein.* (Maps of region east of Jordan.)
17. Hudleston, W. H. On the Geology of Palestine. *Proc. Geol. Assoc.,* Vol. 8 (1883), pp. 1–76, Plates 1 and 2.
18. Hull, Ed. "Memoirs of Physiography, Geology, Geography of Arabia, Petrea, Palestine," etc., from *Summary of Western Palestine,* Part 5. Published for the Palestine Exploration Fund by Alexander P. Walt, 2 Paternoster Square, 1889.
19. Hume, W. F. *Report on Oil Fields in Region of Egypt.* Cairo, 1916. Contains Geologic map 1/150,000;
———. *Geography and Geology of West-Central Sinai.*
20. Lartet, Louis. "Essai sur la Géologie de la Palestine et des Contrées Avoisinantes." *Ann. des Sciences Geol.,* Vol. 1. Paris, 1869.
21. Lynch, W. F. *Official Report of the U. S. Expedition to Explore the Dead Sea and the River Jordan.* Baltimore, 1852.
22. *Naturwissenschaftl. Studien am Toten Meere und im Jordantal.* (Bericht über die im Jahre 1908 auf Befehl S. Maj. d. Sultans Abdul Hamid unternommene Forschungsexpedition nach Palästina.) Berlin, 1912.
23. Palestine—*Bull. Soc. Geol. France, 2,* Vol. 24, p. 13.
24. Palestine—*Compt. Rend. Acad. Sci. 97,* 1883, p. 491.
25. Palestine—*Zeit. pr. Geol.,* 1903, p. 294.
26. Robinson, E. *Biblical Researches in Palestine, Mount Sinai and Arabia Petraea, 1838.* 3 vols. 8 vo. London, 1841.
27. Schneider, O. *Über das Vorkommen des Asphaltes und Schwefels im Becken des toten Meeres.* Gaea, Bd. 8, 1872.
28. Schumacher, G. *Across the Jordan.* 1886.
———. *Northern Ajilon.* 1890.
———. *Der Scholan.* 1886.
———. *Das Südliche Bisam.* 1897.
29. Steinman and Wilckens. (V-pt. 4.) *Handbuch der Regionalen Geologie.* 17. Heft, Bd. 5, Abt. 4. Heidelberg, 1913. Pp. 159 with bibliog.
30. *Survey of Eastern Palestine.* 1889. Some maps of southern part.
31. *Survey of Western Palestine,* Part 5, "Geology."
32. Syria—*Zeit. f. Angewandte Chemie.* 1903. P. 901.
33. Tristram, H. B. "On the Sulphur and Bitumen Deposit at the Southwest Corner of the Dead Sea." *Rept. Brit. Assoc. 1864* (1865). Sect. p. 73.
34. Western Palestine—Map, scale 1 mile per inch, English Expl. Fund, 1883, 26 sheets; map, scale $\frac{3}{8}$ mile per inch, 1881.

GENERAL OIL GEOLOGY OF COLOMBIA[1]

A. H. GARNER[2]
New York, N.Y.

ABSTRACT

The occurrence of oil seepages in Colombia has been known since the days of Spanish occupation. It was not until the present year, however, that oil was produced in sufficient quantities for export.

Geologically, the country may be divided into six distinct provinces, namely: Upper Magdalena River Valley, Coastal, Cesar River Valley, Maracaibo Basin, Llanos, and Atrato River Valley.

The only commercial production is obtained from the Tropical property in the Upper Magdalena Valley, probably from the upper Eocene or lower Miocene. A small well has been encountered in the Eocene in the Maracaibo Basin. Development in the Coastal area has not met with commercial success although small quantities of oil and gas have been encountered. Great thickness of sediments in Miocene and Pliocene but presence of many seepages and anticlines together with the accessibility make it worthy of further testing.

INTRODUCTION

The occurrence of oil seepages in Colombia has been known since the early days of Spanish occupation. It was not until the present year, however, that oil has been produced in quantities sufficient for export. Development work has progressed slowly for several reasons, and to date petroleum has been encountered in quantity in only one field.

Considerable geological work has been done in Colombia by several companies, but most of the data obtained are buried in company files, and published literature is meager.

Colombia is situated in the northwestern part of the South American continent, bordering on the Caribbean Sea at the north and the Pacific Ocean at the west. It has a great distance bordering on these bodies of water and many good seaports.

Although it was one of the first countries of the New World visited by the early Spanish explorers, the development of its natural resources and its normal increase in population have been retarded by civil wars and climatic conditions. At present approximately ten million people live within its boundaries, and the country has embarked upon a new era of development embracing ambitious plans of opening up new highways and railroads.

CLIMATE AND TOPOGRAPHY

Although the climate is everywhere characteristically tropical, it varies with the topography and is in only a few localities excessively hot or abnormally un-

[1] Paper read before the Association by J. T. Duce at the New York Meeting, November 15, 1926. Manuscript received by the editor December 5, 1926.

[2] Brokaw, Dixon, Garner, and McKee, geologists and petroleum engineers, 120 Broadway, New York, N.Y.

healthful. There are seasons of excessive rainfall, such as in October and November, but during the rest of the year there is little or no precipitation.

Much of the country is heavily forested, but areas like that along the Caribbean coast southwest of Puerto Colombia, many places in the northern Magdalena Valley, and the llanos region contain open, grassy plains or are covered only by a semi-arid type of brush growth.

The main topographic features of the country are the three roughly parallel high mountain ranges extending in a northerly direction from a common center in the south and disappearing before reaching the north coast.

GEOLOGY

For the purpose of a geological discussion of the oil possibilities of Colombia, the country may be divided into six distinct areas. These are the Upper Magdalena River Valley, the llanos, the coastal region, the Maracaibo Basin, the Atrato River Valley, and the Cesar River Valley.

UPPER MAGDALENA RIVER VALLEY

The Upper Magdalena River Valley is considered as that part of the drainage area of Magdalena River lying south of the town of El Banco, with the Cordillera Central on the west and the Cordillera Oriental on the east. This is a long, narrow basin of deposition with mountains on the two long sides. The two ranges of mountains are made up of igneous and metamorphic rocks, and although they have little bearing on petroleum resources, they serve to delineate the inclosed sedimentary basin. Rocks of Cretaceous and possibly Jurassic age are exposed on the flanks of the mountains. Overlying these sediments are rocks that are considered to be Eocene, Miocene, and Pliocene in age.

The relation of the rocks of different ages has not been definitely established, but it is believed there exists an unconformity between the Cretaceous and Eocene, one between the Miocene and Pliocene, and probably a small one between the Eocene and Miocene.

From the little information obtainable in this area, it is believed that there is a great similarity to, or duplication of, the geological section on the two sides of the Cordillera Oriental. The following is the section in the District of Colon and the southern part of the District of Perijá in Venezuela, and the writer feels confident that this section may be found applicable to the Magdalena Basin, particularly in the Cretaceous and Eocene.

GEOLOGIC SECTION IN THE DISTRICT OF COLON

Pliocene.....	1,000± feet, La Villa formation (mottled sands and clays)
Miocene	6,000± feet, Arimpia formation (mottled sands and clays)
Oligocene.....	2,000± feet, Rio de Oro formation (shale and sandstones)
Eocene.....	800± feet, Mirador sandstone
	1,200± feet, Lora coal measures
Cretaceous.....	2,500± feet, Rio Mito Juan shale
	750± feet, La Luna limestone
	2,500± feet, Rio Cogollo limestone

In this area—especially in its northern part—there is a very prominent formation consisting of gravels and conglomerates, which is flat in most localities, although it has also been observed standing on edge. It is considered to be Pliocene in age. This formation is of relatively little importance as to petroleum, but it forms an obstacle to the study of the more important underlying formations.

The most prominent structural features in this basin are lines of weakness and faulting along the foothills of the mountains. It is believed that this movement is progressive and has continued until very recently. Toward the center of the basin are anticlines very steeply folded, narrow in width, but generally long. Many active seepages accompany the faulting and anticlines. It is thought that the great thickness of dark and bituminous shales at the top of the Cretaceous and at the base of the Eocene serve as a source for much of the oil in the seepages and anticlines. Because of the faulting and sharp folding it is thought that oil will migrate upward from the source beds into the first porous overlying beds. As many of the Eocene sandstones are quartzitic and non-porous, it is most probable that production is obtained from the Upper Eocene or Lower Miocene.

The Magdalena River Valley is the scene of active development. Companies owning leases and drilling or planning to drill are the Tropical Oil Company, South American Gulf Oil Company, Leonard Oil Exploration Company, Colombian Syndicate, Magdalena Syndicate, Equatorial Oil Company, and Rico Oil Company.

The Tropical Oil Company has developed a production estimated up to 75,000 barrels a day. The gravity of the oil is reported to be approximately 29° Baumé. The average depth of the wells is less than 2,000 feet. Although most of the oil comes from the Infantas anticline, it is reported that successful wells have been drilled on two more anticlines. The oil is shipped to the coast at Cartagena through a 10-inch pipe line having nine pumping stations. The construction of this pipe line was an excellent piece of engineering, completed at a reported cost of $20,000,000. It is reported that the construction of a duplicate line has been commenced. Active development is being commenced by the South American Gulf, Colombia Syndicate, and the Magdalena Syndicate. Because of the generally similar conditions existing throughout the basin, it is reasonable to assume that some of these tests will result in the development of new fields.

LLANOS REGION

The llanos region is considered as the large area draining into Orinoco River and its branches and situated east and southeast of Bogotá and the Cordillera Oriental. Due to its location, it is only natural that little is known of the geology of this region, but it is reliably reported that there are many oil seepages and probable anticlines along the foothill belt.

It is believed that the rocks exposed will be found to be the same as, or similar to, those exposed in the Magdalena River Basin and in the southwestern part of the Maracaibo Basin. While this area may be considered inaccessible by many, a careful study of the map will indicate routes of entrance and exit either through the plains of Venezuela or to Lake Maracaibo.

COASTAL REGION

The coastal region is considered as the territory extending along the coast of the Caribbean Sea between the Magdalena and Atrato rivers and to the south as far as a line drawn between El Banco and the mouth of Atrato River.

This is essentially a plains area, although there are many small hills throughout its extent. The northeastern and eastern parts support a semi-arid type of vegetation, but the western area is more humid and in many parts densely forested.

The rocks exposed in this region range in age from Eocene to Recent. A hard, cherty limestone forms hills in the areas east of Cartagena and east of Lorica. This appears to be the basal rock, and is believed to be Eocene.

A typical section in the vicinity of the Sinu River Valley is as follows:

GEOLOGIC SECTION REPRESENTING THE COASTAL REGION OF COLOMBIA

Pliocene and Upper Miocene	Sandstones, clays, and conglomerates (4,000± feet)
Middle Miocene	Dark gray shales (450± feet)
	Light gray calcareous shales (1,600± feet)
	Interlaminated sandstones and gray shales (800± feet)
	Buff and blue calcareous, massive sandstones forming hogbacks (600± feet)
	Light gray calcareous shales (1,600± feet)
Lower Miocene	Blue, soft, massive shale with soft, calcareous sandstones (1,500± feet)
Oligocene	Gray shale with massive nummulitic limestone lenses

Many oil seeps occur near the upper contact of the Lower Miocene shale.

A typical section near Puerto Colombia does not go below the upper part of the Middle Miocene, with more sandstones and grits above the gray shales.

In the vicinity of Sincelejo, El Carmen, and San Andres the rocks are essentially a series of sandstones and shales, probably ranging in age from the Lower Miocene upward.

It will be noticed that in this area the older sediments generally are exposed in the south and the younger ones in the north. Throughout this region the beds of rocks have undergone intense folding, resulting in many small and very sharp anticlines and many faults of little throw. In most places the strike of both folds and faults is in a northerly or northeasterly direction. Oil and gas seepages and large mud volcanoes are of very common occurrence. As many as 150 oil seepages have been reported.

This area has been the scene of several attempts to develop oil production. Some of the wells were located on a basis of surface shows of oil rather than on underlying structure, and to date no development has met with commercial success.

In the first stage of development wells were drilled by the Standard Oil Company of New York in the vicinity of Lorica, on Sinu River. None of these reached a great depth and all were abandoned. Just south of Puerto Colombia seven wells were drilled by an English group, and although small quantities of light oil and fairly large amounts of gas were encountered, the result was not considered commercially successful.

Within the last few years other attempts have been made. In the Sinu Valley west of Monteria two wells have been commenced by an English group and so far have not encountered commercial oil, although the wells are reported to be 2,700 and 1,800 feet in depth. In the region south of Puerto Colombia the same English group and the Standard Oil Company of California are each drilling a well. Mechanical difficulty in drilling through a caving shale has delayed reaching a depth of more than 1,800 feet.

The South American Gulf Company has drilled deep test wells at San Andres and the Standard Oil Company of California has done the same at El Carmen. Some of the former are reported to have had good oil shows.

While the results of drilling in this area have not been successful to date, the writer feels that in view of the accessibility, many seepages, and anticlines such a large area is still worthy of many more test wells.

MARACAIBO LAKE REGION

The Maracaibo Lake Region is an area lying principally in the Department of North Santander with the Cordillera Oriental on the west and the main Venezuelan Andes on the southeast. It is all in the drainage basin of Lake Maracaibo.

This is generally a forested, sparsely inhabited country, with some coffee-growing in the vicinity of the city of Cucuta.

Geologically it is intimately associated with the District of Colon in Venezuela. Rocks of Cretaceous and Eocene age predominate. They are folded in long, steeply dipping anticlines with many seepages of light oil.

A shallow well estimated to be good for 500 barrels was drilled some years ago by the Colombian Petroleum Company on an anticline near the mouth of Rio de Oro.

This region is considered to hold great possibilities for large production of good quality oil. Although its development has been delayed, in large part because of its location, this condition should not long continue to be a hindrance.

ATRATO RIVER DISTRICT

This division is regarded as including the valley of Atrato River. Little is known of this area. It is reported to be heavily wooded, rather hot and unhealthful, and few geologists have made examinations here. There are persistent reports of low-dipping sedimentary rocks and oil seepages. Much of the northern part of this area has been considered by the government for national reserve.

CESAR RIVER VALLEY

This region is considered to be the territory extending from El Banco in a northeasterly direction in the valley of Cesar River.

It is essentially a semi-arid type of country with many open, grassy plains and some thick forests along the streams. It is only sparsely populated and most of the people are engaged in cattle-raising. Cesar River is navigable for an appreciable distance by barges and small boats most of the year.

Little is known of the geology here, but the area is believed to be a rather long, narrow basin of deposition between the Perijá Mountains on the east and the probable extension of the Cordillera Central on the west. The granite Santa Marta Mountains lie on the northwest.

The typical Venezuelan geological section of the black Cretaceous shales and limestone, overlain by the typical Eocene coal series and massive sandstones, is exposed in the foothills and valley. There are reports of oil seepages and oil shales, probably in the Cretaceous. It is believed that the younger rocks are more predominant on the north.

THE SEARCH FOR OIL IN NEW GUINEA[1]

ARTHUR WADE[2]
London, England

ABSTRACT

Exploratory work in New Guinea is dangerous because of almost impenetrable forests, tropical diseases, unfavorable climatic conditions, hostility of uncivilized natives, and lack of interest by the Dutch in developing the area. The island of New Guinea is divided into three administrative parts, Dutch New Guinea, former German New Guinea, now under Australian mandate, and former British Papua, now under Australian mandate. The island is in one of the greatest zones of crustal weakness of the earth, which is described by a series of arcs extending from the Himalayas to New Zealand. Complex structural conditions are explained by great overthrusts. Tertiary sediments, intensely folded, mainly of shallow-water types, contain the evidences of petroleum, oil and gas seepages, brackish springs, and mud volcanoes. Beneath the Tertiary deposits the formations range from Mesozoic to Archaean.

DIFFICULTIES OF EXPLORATION

Omitting the more or less continental areas, such as Greenland and Australia, New Guinea is the largest island in the world, having an area of more than 300,000 square miles. Madagascar and Borneo are its nearest rivals in size, and indeed all three cover remarkably similar areas.

New Guinea, it is worthy of note, is still the least-known tropical area in the world. The greater part of the interior has never yet been trodden by the foot of the white man and is as difficult of access as the Polar regions. The difficulties are not the same, of course, as those encountered around the Poles, but they are sufficiently formidable to make the task of exploration one of serious magnitude. In the dense tropical forests and tangled swamps, which cover the greater part of the littoral belts, every inch of the way has to be cut, and very frequently one is happy at the end of the day if a distance of four miles has been traversed. After an arduous trek of this description, I once described my feelings as being those of a caterpillar eating its way through the heart of an infinite cabbage. One really has to bore a tunnel through an interlacing and thorny maze of vegetation which covers mountain, hill, and valley, the only breaks being those cut by the rivers and more considerable streams.

The rainfall varies considerably from place to place. There are dry areas, such as that around Port Moresby, the seat of government in Papua, where the rainfall may be as low as from 30 to 40 inches per annum, and there are areas where as much as from 500 to 600 inches of rain may fall in the course of a year. I suppose

[1] Paper read before the Association by Sidney Powers, at the New York Meeting, November 17, 1926.

[2] Consulting Geologist, 19 Basinghall Street, London, E.C. 2, England. Introduced by Frederick G. Clapp.

that the average rainfall for the whole of the country would exceed 100 inches per annum, and possibly be as high as 150 inches. Consequently there is a wonderfully well-developed river system, and, since axial ranges of mountains traverse the country from east to west, the rivers are evenly distributed. This is a fortunate circumstance, since the rivers are usually navigable by launch for considerable distances, Fly River, for instance, having been so traversed for more than 600 miles from the mouth. Thus the rivers provide the best and most expeditious highways into the interior, and afford, to some extent, limits to the amount of cross-country work that is necessary for exploration. The rivers are infested with alligators in their lower reaches and are full of snags and timber jams. Whirlpools, which may be dangerous, are met with in the higher reaches, where rock bars, canyons and gorges, rapids and cascades may also impede progress. Moreover, the heavy rainfall causes the rivers to be subject to sudden and damaging floods. A rise of 30 feet in less than an hour has been noted on Vailala River. The flood waters carry with them huge trees and tangled masses of soil and timber like floating islands. In such times no vessel is safe on the face of the waters, which may spread inland for miles over the adjacent country. But the broad and easy-flowing stream is not always a safe place for the explorer. The native tribes in new country may resent his intrusion, and he becomes uncomfortably aware of the fact if they show their hostility by following his course with flights of arrows or spears unpleasantly barbed and sometimes tipped with sharpened and barbed pieces of bone. Fortunately the Government is gradually extending the area under control by the establishment of police stations with a white magistrate in charge and by a system of patrols, in which there is an effort to combine the ordinary functions of government and the policing of the country with the work of exploration. The work of some of these patrol officers deserves to be better known, for in some cases it compares very favorably with the better-known adventures of the North West Mounted Police.

The hostility of natives may be particularly dangerous in cross-country work. The native is at home in the forest, through which he can travel quickly and almost invisibly. He can attack and remain unseen. The explorer may go forward for days with a party of natives at his heels and be quite oblivious of the fact. However, not every native is hostile who has never before seen white men, and sometimes friendly relations can be established by the exercise of tact, discretion, and patience.

Finally, the highly folded sedimentary deposits of the littoral regions have been subjected to intense erosion. High ridges are frequently encountered with sharply concave flanks on both sides, the summit being a mere knife-edge of rapidly crumbling material. Sometimes it is impossible either to cross or to travel along such a ridge even with the assistance of the complete cover of trees and other vegetation, and days may be lost in finding a way around. Native villages are sometimes built on wider parts of such ridges six or seven thousand feet above sea-level, and cases are known where the natives can communicate with the inhabitants

of a village similarly situated on a parallel ridge by shouting in a peculiar, singsong drawl, although it may take many days to walk from one village to the other, the only possible track being along the knife-edge till it dies away in some valley many miles away, and back along a similar track on the second ridge. Since such ridges usually run parallel to the coast, or the main east-and-west axis of the country, they absolutely preclude any direct route into the interior. Tree-clad precipices more than 1,000 feet sheer have held up our own expeditions for days. The most remarkable precipice that we know of in the world is in Dutch Guinea, where, near Mount Leonard Darwin, there is a sheer drop of 10,500 feet.

Add to all these difficulties the prevalence of tropical diseases such as malaria, the intense humidity of the atmosphere, terrific tropical thunderstorms, cyclones of a type peculiar to New Guinea, and the discomforts due to a bewildering variety of insects, leeches, and other peculiar and unpleasant forms of life, and it will be realized that the work of the prospector for petroleum in the forest and swamp areas of New Guinea is one that calls for qualities of mind and body that are out of the ordinary.

BROAD GEOLOGICAL FEATURES AND TECTONIC RELATIONS

Sometimes it is possible to deal with a geological problem as one that affects a limited geographical area only. It is remarkable, however, how frequently the solution of such a local problem is found to have much wider significance and to shed light at unexpected times and places. In dealing with the general geological features of New Guinea we can look as far as the Himalayas on the one hand and New Zealand on the other. One of the greatest zones of crustal weakness of the globe is that which swings in a series of arcs from the Himalayas to New Zealand. This island constitutes part of what Brouwer has called the New Zealand–New Guinea Arc (XIV, p. 47).[1] Stanley, following Suess, would, with good reason, subdivide this arc, calling the part affecting New Guinea the First Australian Arc (XII, p. 54). The tectonics of this most interesting region have been dealt with by David (VI, pp. 316–25), and in more detail by Brouwer (XIV, pp. 46 ff.), and, as affecting New Guinea itself, by Stanley (X, pp. 7 ff. and XII). Though from my own work in Portuguese Timor and in New Guinea it would perhaps be possible to supplement the observations of these authorities and to fill in some of the gaps, it would take up too much space in a paper which is to deal primarily with petroleum research. I will, therefore, cover the ground as briefly as possible.

Mountain-building movements have been at work since pre-Tertiary times along the entire zone from the Himalayas to New Zealand, and are still at work in places. In Tertiary times geanticlinal conditions, represented by the present folded mountain axes, resulted in the formation of a string of islands, of lesser extent than at present, extending from Burma to and beyond New Guinea. The accompanying and parallel geosynclines were submerged, and in them accumulated enormous thicknesses of shallow water deposits in Tertiary times, con-

[1] Numbers in text refer to Bibliography at end of this article.

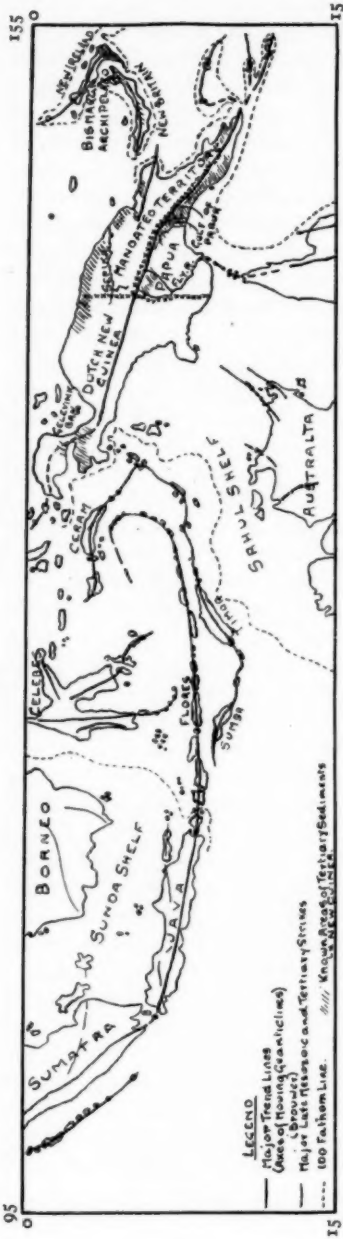


FIG. 1.—The major tectonic features of New Guinea and neighboring territories. Based on maps by Brouwer, Stanley, David, and Wade. Map drawn by A. Wade, October, 1926.

sisting for the most part of clays, sands, grits, and thin limestones containing an abundance of organic remains. Seams of coal and lignite occur from place to place and differ greatly in thickness and in character. In the sands and clays impressions of leaves and stems are plentiful. In New Guinea a thick series of grits and conglomerates forms the basal beds of the Tertiary deposits, which, so far as is known, form an unbroken sequence up to the Pliocene, upon which marine sediments and coral reefs of Pleistocene age rest with marked unconformity. This unconformity, which is well seen in New Guinea, Timor, and other islands, is due to two causes: (1) the alteration in sea-level, which took place in Pleistocene times at the close of the Ice Age, and (2) positive movements of the land areas. These Tertiary sediments are remarkably similar in character from Burma to New Guinea, and in them the oil fields of Burma, Sumatra, Java, and Borneo have been developed; also, in Timor, Ceram, New Guinea, and other islands seepages and other evidences of the existence of petroleum are plentiful and widespread.

The Tertiary deposits in the geosynclines have generally been subjected to folding movements. Long, broad, dome-like folds, generally asymmetrical, extending parallel to the main tectonic axes, characterize the more important oil-field areas, the structures becoming more pinched and complicated as we pass from Burma in the direction of Java. As we approach New Guinea the

presence of the old continental mass of Australia begins to affect the nature of the folding. This mass has acted as a "horst," to which the mountain ranges of New Guinea bear a similar relationship as do the Himalayas to the Indian peninsula, and there is a crumpling of the strata which has resulted in overfolding and overthrusting in this direction. The New Guinea arc is broken at both ends toward Timor and the Bismarck Archipelago, coincidently east and west of the Australian land mass. There is a virgation of the East Indian arc from Timor to Ceram, which pushes forward and turns back on itself, accommodating itself to the outlines of the Australian coast on the south and east and to the parallel arc of New Guinea on the north. A similar virgation and curving back is apparent in the Bismark Archipelago and in the islands off the eastern extremity of New Guinea. In Timor great overthrusting is present. While the central axis of New Guinea has been lifted high, faulted, and crumpled against the Australian mass on the south, it seems that east and west of this mass, in the Timor curve and the curves east of New Guinea, the strata have been thrust gradually and progressively forward, curling round the Australian block at its edges or exactly at those places where relief could be best obtained by horizontal thrusting movement. It is just as though one pressed a mass of clay against the end of a box. The clay would crumple and lift against the obstruction of the box, but would be thrust forward round the edges.

Although the foregoing discussion may at first appear to be of merely academic interest, the facts may have a bearing on the distribution of oil fields in this region. The most productive of the proved oil-bearing areas are those farthest removed from the effects of the Australian "horst." Although excellent surface indications of oil and gas are to be found in Timor and New Guinea, no production on a commercial scale has been obtained. The great overthrusts in Timor complicate the geological problem in that country for the prospector for oil. The amount of oil of good quality present in some of the surface deposits justifies the hope that good supplies will eventually be obtained. It may be that the types of occurrence are what may be called line accumulations against faults, or migratory accumulations along thrust planes. Great masses of Jurassic limestones and possibly even older rocks have been thrust over the Tertiary deposits in places so that it is almost useless to look for normal conditions of accumulation. In any case the problem of location is far from easy. The most remarkable seepage I have ever seen occurs near the south coast of Portuguese Timor. Atalele River flows over limestones of Mesozoic age broken in places by bars of igneous rock, andesites, and coarse dolerites. In the limestone bed of the river stands an isolated block of limestone, a rough cube with sides of 10 or 12 feet. One can walk completely around it. Solution has worn channels in the base of the block so that one can see underneath it to some extent, and yet on the top is a low conical mound of bituminous matter 5 or 6 feet in diameter which was burning for days under my observation and was reported by the natives of the district to have been burning for years. The mound has a small crater-like orifice near its apex through which it is apparently being fed

from below. It has every appearance of a true seepage of viscous bitumen or heavy crude petroleum. I examined the occurrence very carefully and many times and have come to the conclusion that the block has been carved out *in situ*, that a fissure from below runs through it along which a heavy crude oil is seeping, that this bituminous matter has partly filled the bedding plane at the base of the block and by oxidizing has formed a kind of impervious cement with a central channel which allows access to the summit of the block, and that the fissure is kept open by the constant slow movement of the seeping matter.

In New Guinea similar types of Tertiary deposits are present on both sides of the high mountain ranges which form the axis of the country, but, as may be expected, the soft strata are intensely folded. Here, too, long dome-like folds are a characteristic feature, but they are more pinched and there is a greater tendency toward overfolding than in the proved oil-field regions mentioned. Moreover, as is to be expected in such circumstances, lines of fracture in many places traverse the crests of the folds approximately along the strike. These features not only demand great care in the selection of drilling sites, but make difficult the task of the driller. Apart, however, from these problems, there is the more important consideration as to how far accumulation has been affected or checked by such movements in the strata. I have stated elsewhere that it is my opinion that comparatively small isolated pools are possible, and some of these should be profitable to exploit. This opinion is based on the fact that in some of the oil fields of Sumatra conditions exist which can be almost exactly paralleled in New Guinea. No reasons have been brought to my knowledge, up to the present, that would cause me to think that conditions are less favorable in some parts of New Guinea than they are in some parts of Sumatra.

POLITICAL DIVISIONS

The island of New Guinea is divided into three administrative parts. That part of the island west of the 141st Meridian is a Dutch possession and covers an area of 150,000 square miles. The remainder is divided by the main watershed formed by the mountain axis. The northern part, with an area of 72,000 square miles, was formerly German New Guinea and is now mandated to the Commonwealth of Australia. The southern part, 90,000 square miles in extent, is the old British possession of Papua, now also administered by the Commonwealth Government. It is convenient to deal with each of these divisions separately.

PAPUA

Oil was discovered in Papua in 1911 by a local planter. Seepages of oil and gas were found about 30 miles by river from the mouth of Vailala River, which flows into the Gulf of Papua, near its head in country which was then unexplored and practically unknown. The natives of the district had long known of the small mud volcanoes and bubbling pools, but since they regarded them as being due to the agencies of evil spirits they not only avoided the localities but were

loath to give any information concerning them. In consequence of the discovery, J. E. Carne, who had been engaged by the Commonwealth Government to investigate coal deposits in the Gulf region early in 1912, took the opportunity to look into these occurrences of petroleum also and embodied his results in a report to the Commonwealth Government (III). E. R. Stanley, the government geologist of Papua, covered a wider area shortly afterward and added to existing knowledge as to the distribution of surface manifestations (IV).

FIG. 2.—Unexplored country at headwaters of Vailala, near old German boundary. View taken from top of precipice 1,000 feet sheer. Photograph by A. Wade.

A miniature boom followed and both individuals and companies staked out claims which were set aside in 1913, when the Commonwealth Government decided to reserve the whole area and declared its intention to test the oil-bearing possibilities as a Government monopoly. Under Government auspices a light hand-drilling outfit started work at Upoia, on the Vailala River, and a little later a standard rig with tubular derrick of Australian make commenced operations on the opposite bank of the river; curiously enough, under separate management. Later in the year the Commonwealth Government requested me to make a more thorough examination of the region with a view to advising them as to future development and policy. With a little band of enthusiastic assistants we made a reconnaissance of the whole of the Gulf region, from Kikori River in the great Delta region to Yule Island, covering more than 2,000 square miles and mapping

every occurrence of oil and gas concerning which information could be obtained. Geological mapping was done in some important areas in such detail as the time that could be allotted to them would permit. It was largely a work of exploration, and much topographical mapping had to be done. The whole of the coast line of the area had to be re-surveyed, owing to existing inaccuracies and omissions, and some rivers and creeks were mapped for the first time. This was necessary in order accurately to tie in to the coast line the inland areas where discoveries had been made. To get an idea as to the inland range, the changes in character, and the general structure of the Tertiary deposits, we followed the Vailala up to its headwaters as far as we could toward the main ranges, an area never before traversed by white man. We found the basal beds of the Tertiary, affected by intrusions of andesite, but had to turn back near the German boundary, partly owing to the fact that further progress was blocked by precipices more than 1,000 feet sheer, and partly because of sickness among the members of the party. The results of this work were embodied in a Parliamentary Paper (V). In consequence of the recommendations made in this report it was decided to press forward with a scheme of development. In 1915 the work was organized for the first time and I was put in control. A number of bores were put down in the Vailala area and a few thousand gallons of light, straw-colored oil were obtained, together with some considerable outbursts of gas, but no production that would be of commercial importance in Papua. In 1918 the Australian Government made a limited agreement with the British Government to share the expenses of further work, and the Anglo-Persian Company was put in control of the combined effort. Operations were transferred to a long, domed flexure near Popo, nearer to Yule Island, but though considerable drilling has been done and a bore carried nearly to 3,000 feet, so far as the production of oil is concerned, the work has not yet been so successful as that done in the Vailala area. Production is looked for, however, at still greater depth.

FIG. 3.—The first bore at Upoia, Vailala River, Papua. Second derrick, the first having been demolished by falling tree. Photograph by A. Wade.

In 1922 the Government abandoned its reserve of the whole area, reserving only an area around Popo. The rest of the field was thrown open to private enterprise. Companies with Australian capital have taken up areas on prospecting licenses, one now being at work in the Vailala region near the coast. Encouraging signs have been met with in a boring on the Hohoro Anticline near the mouth of the Vailala, but the bore has not yet been carried to sufficient depth to test the area adequately. In any case, one bore hole may not be a sufficient test of the kind of structure that exists. Any accumulation is likely to be in the form of a long and narrow pool, and it may have been found difficult, in the selection of the first site, to make sufficient allowance for the asymmetrical nature of the folding.

FIG. 4.—The first combination standard and rotary rig and 88-foot derrick at Orevi, Vailala River, Papua. Photograph by A. Wade.

GEOLOGY

The only evidences of the existence of petroleum in Papua have been found in the Upper Tertiary sediments. Shallow water types predominate, brackish water or marine, indicating the proximity of river estuaries and deltas. Consequently there is considerable variation from place to place in the nature of the deposits. The more psammitic types are lenticular and erratic; limestones, especially where interbedded with pelitic sediments, are thin, inconsistent, clayey, and practically yield no fossils; where associated with psammitic types they are more massive and yield many fossils. Pelitic types predominate in the upper part of the Tertiary deposits, beds of dark blue and gray clay, more than 1,000 feet thick, occurring in the Miocene. Psammitic types probably predominate in the lower part of the Tertiary sediments.

In the country bordering the Gulf of Papua the generalized sequence is as follows:

GEOLOGIC SEQUENCE ON THE GULF OF PAPUA

Recent	Estuarine, delta, swamp and river muds, sands and pebble-beds. River terraces and raised beaches
Pleistocene	Upraised, massive coral limestones with mudstones interbedded near base. Gravels and sands
	Unconformity
Pliocene	Fossiliferous mudstones, sandstones, conglomerates, calcareous grits, and limestones folded with underlying strata. Porphyritic lavas and andesites
Miocene	
Upper	Fossiliferous mudstones, sandstones, calcareous grits, and limestones. Seams of lignitic coal. Upper oil horizon of the Vailala region
Middle	Blue clays, mudstones and marls with thin limestone partings, soft sandstones and hard calcareous grits; fossiliferous. Lower oil and gas horizon of the Vailala region
Lower	Similar to preceding. Globigerina chalk in oil borings
Pre-Miocene	Massive grits, sandstones, and conglomerates, in places calcareous and showing thin partings of coal

Similar deposits of the same age on the northern side of the watershed in the Mandated Territory of New Guinea have been estimated to be more than 15,000 feet thick. The total thickness of these sediments in Papua has not been estimated, owing to intense folding and the frequent occurrence of strike faults. It can scarcely be less than in the Mandated Territory. It has been estimated that the Pliocene deposits in this part of Papua attain a thickness of more than 3,000 feet in places, and the Upper Miocene may range to nearly 6,000 feet in thickness. These estimates, however, may be exaggerations, for strike faults may be present which would greatly increase the apparent thickness of the strata, and such faults often escape observation in a thick, folded, and more or less plastic mudstone series—in fact there may be nothing whatever that is observable unless harder beds are present.

Beneath these Tertiary deposits, formations ranging from the Mesozoic to the Archaean are known in New Guinea. Strata consisting chiefly of massive limestones and shales of the Cretaceous and Jurassic ages are well developed along the main ranges and will eventually be correlated with similar formations known to exist in Timor and other islands of the East Indian Archipelago.

Strata ranging from Devonian limestones through sedimentary Cambrian and Precambrian to Algonkian (?) phyllites and quartzites, and schists and gneisses of the Archaean, associated with both acid and basic intrusives, seem to be a continuation of North Australian geology in the central parts of New Guinea (XIII). When these groups come to be studied very powerful illumination will be shed on the early geological history of the Australian continent and this part of the world in general.

The Tertiary beds in the Gulf region of Papua are intensely folded and to some extent fractured. Many strike faults have been noted, but the amount of displace-

FIG. 5.—Burning off Anglo-Persian Company's camp site, Popo location. Photograph by A. Wade.

FIG. 6.—Pulling boiler up to location at Popo. Photograph by A. Wade

ment in the coastal areas is, as a rule, of moderate dimensions. The more important folds are in the form of narrow and elongated closed structures extending from W. NW. to E. SE., parallel with the main axis of the country, but there are im-

portant virgations, especially near the coast in the Vailala country, where abrupt changes take place in the direction of the strike, which may extend almost due north and south or a little east and west of this direction, thus showing Australian influences and a tendency to take up trend lines which are characteristic of eastern parts of Northern Australia. Thus these movements, affecting the continental mass of Australia, must have been active down to Pleistocene times and have had their effects on the land masses on the north.

In some places, as at Popo, wide synclinal depressions border the pinched anticlines and should favor accumulation of petroleum in the uplifted areas. Some remarks made by Brouwer as to conditions in the Dutch East Indies may apply equally well to New Guinea. He says (XIV, p. 121):

> Moreover the deposits show a considerable variation in character, that is, they represent conditions that were not always favorable to the accumulation of oil. Thick series of pelitic sediments without sufficient psammitic beds between them are found, for instance in the eastern part of Central Sumatra. In this region oil and gas emerge from Palaeogene sediments but no workable deposits have yet been found.

Although conditions must have been favorable to the formation of oil over great areas in New Guinea, the presence of conditions such as those referred to by Brouwer may have prevented accumulation, which may also have been checked elsewhere by too early and too pronounced folding.

DRILLING

The first drilling done in Papua was by a hand-boring plant which was actually successful in striking a good showing of light oil at about 190 feet. A standard rig of American type with 88-foot derrick was not erected until after I took charge in 1915, the timbers being cut by our own sawmill from logs obtained in the surrounding forest. Some of the forest timbers are of excellent quality both as to hard and soft woods, but it is difficult to get them seasoned properly, and eventually we found it better to import Oregon pine.

Great difficulty was experienced in dealing with heaving muds met with as drilling proceeded. Drive pipe was used, but it was impossible to drive through these muds which persisted from about 450 to more than 600 feet in depth. I have seen the casing pushed out of the hole by the action of the mud till a column of mud rose 60 feet above the derrick floor. A circulating head was fitted to the casing, mud pumps installed, and a system of flushing tried, along with percussion drilling, but it proved to be of little advantage. The casing was eventually worked through the muds by long and persistent efforts. In a subsequent bore a combination percussion and rotary rig of standard American type was used. It is obvious, however, that the use of a mud-flush against mud can be of no advantage. It is useless to try to force mud into a wall of mud in order to make it stand up; though the drillers, who were enthusiastic rotary men, were much surprised. A system of pulling the casing through the mud was next tried. A deep cellar was excavated around the casing with two heavy balks of timber at the bottom. The cellar was

lined with timber above and resting on the balks. In slots cut in the balks were fixed two crown wheels. A spider was attached to the casing-head with a pulley-block secured to each leg. A line was then run from the calf-wheel through the wheels in the balks of timber and through the pulley-blocks. It was then possible to run in the tools and to exert a powerful downward pull on the casing from the calf-wheel. The casing was thus pulled in through the mud instead of being driven in. Some success was obtained by this method, though it is not one I can recommend generally.

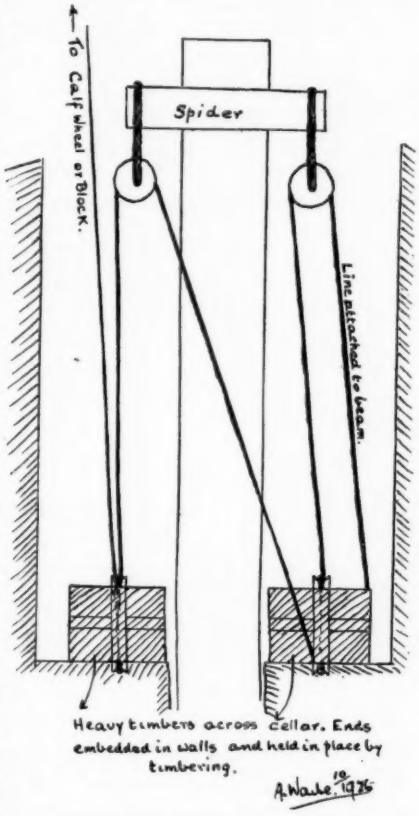

To Calf wheel or Block.
Spider
Line attached to beam
Heavy timbers across cellar. Ends embedded in walls and held in place by timbering.
A. Wade. 19/1926

FIG. 7.—Method used to pull in casing

The latest well drilled by the Anglo-Persian Company at Popo met with similar difficulties, but at greater depth. Heaving muds started to trouble the drillers, who were using a Falck rotary system of drilling with a reversed flush, at about 2,000 feet, and caused the well to be abandoned at about 2,800 feet. Experience seems to indicate that these heaving muds are probably most troublesome where the anticlinal crests are crushed and much broken. The folds are very much like the waves of the sea. They may be more or less normal and unbroken toward the pitching ends, and overfolded and broken, like the center of a wave breaking on a shallow shore, in the central parts. Of two wells about 400 yards apart on the same structure, one was drilled to nearly 2,000 feet without encountering trouble from heaving mud and the second was in difficulty at about 450 feet. In the first case drilling was easy for percussion tools, more than 300 feet a day being accomplished on several occasions. It is clear that the geologist can be of great service to the driller in such country, and, by careful selection of drilling sites, can help him to avoid trouble. Experience is still the greatest of teachers, and if we now know what to avoid, the lesson has been of great value.

The first seepages noted by Carne (III, pp. 50–51) were of heavy oil of blackish-brown color, dark yellow in transmitted light. The oil from which this sample was obtained had probably been seriously affected by exposure.

The specific gravity was 0.9744, and a sample tested at the Tjepoe refinery gave the following results:

ANALYSIS OF SEEPAGE OIL

No benzine
Boiling point, 230° C.
Between 230° and 300°.....20 per cent kerosene distilled
At 325°.....25 per cent kerosene distilled
Residue.....50 per cent good lubricating oil

But oil from the first shallow bore hole was very different in character.

ANALYSIS OF OIL FROM *No. 1 Bore* (*V, p. 30*)

Reddish-brown mobile oil showing bluish fluorescence
Specific gravity of 15° C., 0.802
Bromine absorption, 3.27
Flash point, under 20° C.
Contained 2 per cent of paraffin wax

Fraction	Description	Boiling Point	Percentage	S.G.	Flash Point	Bromine Absorption
Light petroleum.	Water white	Under 150° C.	32.5	0.758	Under 20° C.	2.91
Kerosene.....	Lemon yellow with bluish fluorescence	150°–300° C.	58.7	0.822	57° C.	2.80
Lubricating oils and solid hydrocarbons....	Dark brown and solid at ordinary temperatures	Over 300° C.	8.8	.....	.....	.....

ANALYSIS OF OIL FROM *No 5, Bore* (*VIII and IX*)

Light brownish-yellow with bluish fluorescence
Marked absence of pronounced color or odor
Specific gravity at 18.75° C., 0.796.
Only decolorized bromine water after several hours contact
Oil suffered no appreciable loss on shaking with dilute acid or alkali
Absence of sulphur or nitrogen
General characteristics very similar to Borneo petroleum

It was found that a 170° run contained about 11 per cent of aromatic hydrocarbons, these being essentially benzene and toluene, results which again show a close similarity to Borneo petroleum.

A comparison between the principal petroleums of the East Indian oil fields and that from Papua shows a close relationship, especially between the petroleums of Papua and Sumatra.

ANALYSES OF OIL FROM PAPUA, BORNEO, AND SUMATRA

	S.G. of Crude Oil	"Benzine" to 150° (Per Cent)	Kerosene 150°–300° (Per Cent)	Residues Above 300° (Per Cent)
Papua.....	0.796–0.802	36	46	17
Borneo.....	0.83 –0.87	19	54	27
Sumatra.....	0.765–0.800	27.1	48.9	14.3

Normal tricosane ($C_{23}H_{48}$), a hydrocarbon which has been identified in brown coals and Pennsylvania petroleum, normal pentacosane ($C_{25}H_{52}$), also identified in Pennsylvania petroleum, as well as normal heptacosane ($C_{27}H_{56}$), a constituent of beeswax, tobacco, and soot, were found. Some of these have been found also in eucalyptus and other natural essential oils.

These discoveries in Papuan crude give strong chemical support to the theory of an organic and indeed vegetable origin for petroleum.

The waters accompanying the seepages and gas blows are always saline; moreover, the waters met with in porous strata during drilling operations were brines.

Two samples obtained from seepages by Mr. Carne gave the following results (III, pp. 48–49):

ANALYSES OF SEEPAGE WATER

	AKAUDA (VAILALA AREA)		ARO-ARO (VAILALA AREA)	
	Grains per Gallon	In 1,000 Parts	Grains per Gallon	In 1,000 Parts
Total solid matter (dried at 220° F.).....	722.20	10.3172	842.60	12.038
Chlorine and chlorides.....	383.70	5.4815	424.62	6.066
Sulphur trioxide as sulphates.....	Nil	Nil	Nil	Nil
	The total solid matter was found to consist largely of sodium chloride with lesser amounts of lime, magnesia, and potash combined as chlorides and carbonates, silica, etc.		Solid matter consisted mainly of sodium chloride with some sodium carbonate, calcium and magnesium carbonates, silica, etc. A strong reaction was obtained for the presence of iodine and boric acid in the water	

The amount of iodine present in some of these brines is as considerable as in occurrences in Java, where it is extracted on a commercial basis. The occurrence of iodine in these brines along with petroleum also has an interesting bearing on the problem of the origin of petroleum.

THE MANDATED TERRITORY OF NEW GUINEA

I have been unable to discover particulars with regard to the discovery of petroleum in late German New Guinea, but the discovery must have been made not many years before the outbreak of war. Baron von Schleinitz was the first to recognize the Tertiary age of the strata forming the north coast toward the estuary of Sepik River, but it was not until 1910 or 1911 that note was made in the

official reports and publications of anything that would suggest the presence of petroleum. About this time the presence of oil seepages in the neighborhood of Eitape, about 80 miles east of the frontier of Dutch New Guinea, became known to the German Government and the Reichstag voted the sum of M. 120,000 toward the purpose of a scientific investigation of this area. Apparently little was accomplished, but several German companies endeavored to obtain monopoly of rights over the possible oil-bearing territory.

Subsequent to the occupation of German New Guinea by the forces of the Commonwealth of Australia in 1914, the coastal area in which seepages were known to occur was visited and reported upon in 1916 by the late E. R. Stanley, government geologist of Papua, and by Captain Macintosh in 1917. Anglo-Persian geologists investigated the Eitape-Madang districts in 1921. Subsequently the Commonwealth Government threw the country open to private enterprise for oil prospecting and development and formulated ordinances to regulate operations. This has led to the formation of several Australian companies who have taken up prospecting licenses over areas along the coast from Matapau to the Dutch border and inland in the basin of Sepik River. These companies have employed their own geologists, but little information of geological value has been issued by them so far, which is natural in the present stage of their operations. Some drilling is in progress near Matapau and Sepik River, and some showings of oil and gas at shallow depths have been met with in bores, but in no case has oil of commercial importance been met with so far, nor has any bore hole been carried to sufficient depth to test the possibilities of the Upper Tertiary strata. For instance, the latest report from Matapau is that a bore is down to 588 feet in gray shales with hard shells, while from Sepik River information received, while writing this paper, indicates that boring has not yet commenced, though preparations are being made. The geology of the area is still under investigation.

Prospectors are being guided very largely by seepages of petroleum, which are more plentiful and, as a rule, more prolific in oil than those observed in Papua. Most of these seepages occur on, or near to, the north coast, but in some places the search has been carried farther inland, where structural conditions rather than surface evidences are of interest.

GEOLOGY

Up to the time of the British occupation of German New Guinea much more geological exploration and research had been carried on in Papua than in the former German Territory, and even today the geology of the littoral region in Papua is better known.

Terraces of coral limestone covering older sediments occur in many places along the north coast of the Mandated Territory and extend into Dutch New Guinea. They may be elevated to more than 1,000 feet above sea-level, as on the north coast of Timor and other islands of the East Indian Archipelago. In age they range to the Pleistocene, and it is thought that some of the higher benches may be even older.

A great belt of Tertiary sediments ranging from the Pliocene down through the Miocene to the older Tertiaries extends almost the whole length of the north coast into Dutch territory. The inland limits of this belt are not known, but they have been traced nearly 200 miles up Sepik River. Beds of similar age occur also on the islands of New Britain and New Ireland.

These strata consist of alternating groups of fossiliferous mudstones, sandy mudstones, grits and conglomerates and limestones, as in Papua. In the Eitape-Madang areas their estimated thickness is more than 15,000 feet. Since these sediments are similar in general nature to those of the same age in Papua, little need be said concerning them. The seepages of petroleum occur in sediments belonging to the Upper Miocene or Plio-Miocene, as in Papua. In general, structural conditions are also similar, though the presence of igneous intrusives in these beds in the eastern part of the coastal area provides new and more complicated features. Along the coastal areas the beds are also very sharply folded and considerably disturbed by faulting. The general strike is, as in Papua, W. NW. and E. SE., and dips range from 30° to 70°. The anticlines are generally asymmetrical, with the steeper dips to the south. Lignitic coal seams are present, but they have not yet received much attention. West of Eitape the country has not been geologically examined, though considerable seepages of oil are known to occur.

It has been suggested that the Tertiary strata may become less sharply folded and less disturbed by faulting and igneous intrusives as they are traced inland from the coast. There is some evidence that this is so in the Sepik Basin toward the boundary of Dutch New Guinea, but too little geological research has been done in these inland areas to encourage positive statements. With regard to folding, it is difficult to believe that the movements have tended to die out toward the main axial ranges in these northern areas. It is certainly otherwise on the southern side of the ranges. These are matters, however, which must remain for further field work to settle.

DUTCH NEW GUINEA

The first reference to petroleum in New Guinea was made by Wichmann, who noted the occurrence of brine, mud, and oil springs in Buti River in the Takar District on the north coast of Dutch New Guinea (XV). Most works of reference also mention an occurrence along with coal in Iwaka River south of the Nassau Range, but omit any authority. I believe the statement can be traced to the report of the British Expedition to Dutch New Guinea in 1910–11. In the account of the expedition the following bald statement is made: "In the low foothills there were strong indications of oil, particularly noticeable in the vicinity of the coal." Further details are lacking (I, p. 248; II, p. 241).

Carne also states that indications of gas and oil have been noted near Fak-Fak, south of the Gulf of MacCluer (III, p. 41), an area in which, according to Brouwer, more or less normal anticlinal structures are to be found (XIV, p. 125). This area is almost due east of the productive oil field on the adjoining island of Ceram.

Oil springs, natural gas, and mud volcanoes are known, not only in Dutch

New Guinea, but on many of the islands near its western coast, such as Celebes, Roti, Timor, Tenimba Islands, Kei Islands, Ceram, and Buton. The oil deposits are in part of Neogene age, but in some cases the age has not been determined. Only in the case of Ceram has any effort been made toward development. Here a small productive field is in operation in the eastern part of the island. So far as Brouwer knows, no oil field has been developed in Dutch New Guinea. But circumstantial rumors have reached the eastern parts of New Guinea and Australia, especially during the war, that production of petroleum was being obtained by the Dutch from at least two areas in their territory, one in the south part of the island, and another in the north. It is also reported that oil has been shipped from these localities to the refineries in Borneo. It is impossible, however, to obtain definite information. For some unknown reason the Dutch have always been very reticent with regard to their New Guinea territory and less is known of it than of the remaining parts of the island. The knowledge that we have of the interior of this territory is very largely due to expeditions led by British explorers. During my visit to Dutch Timor in 1919 I was shown photographs of derricks, thatched with palm leaves in native fashion, which I was assured were taken in the northern part of Dutch New Guinea somewhere near Humboldts Bay. Thus nothing but rumor and indefinite information seems to be available with regard to development in Dutch territory.

It is known, however, that the Upper Tertiary sediments noted in both Papua and the Mandated Territory extend westward into Dutch territory, and that they occupy extensive areas and are similar in character. Normal anticlines, according to Brouwer, exist in western New Guinea, especially south of the Gulf of MacCluer, but the structural conditions in the northern part of the territory are, on the same authority, said to be unfavorable to oil accumulation. It seems probable that some attempts at development have been made, but in any case there is evidence that the vast and almost unknown area covered by the Dutch territory in New Guinea affords a field for geological investigation and research with regard to petroleum which cannot long be neglected.

DISCUSSION

STUART ST. CLAIR: I note with interest that Mr. Wade follows in the footsteps of many geologists who have written on the structure of certain parts of the East Indies. Where complex structural conditions are found they are explained by tremendous overthrusts. From my limited work in certain parts of the East Indies, I am led to believe that we can find more simple explanations for some of these complex structures.

Mr. Wade further states, I believe, that in places Pleistocene corals have been elevated as much as 300 meters or more above sea-level. On one island I found Pleistocene corals, or at the oldest Plio-Pleistocene, at an elevation approximately 1,300 meters above sea-level. It is hard to conceive of such tectonic movement, not volcanic, during only the past 500,000 to 1,000,000 years.

In areas where extensive overthrusts exist, the oil geology is further complicated.

Where there has been extensive vertical uplift in comparatively recent geologic time, and where this movement is probably existent to some degree even now, the position of oil accumulations in relation to structure and water-table may be very uncertain.

W. A. J. M. VAN DER GRACHT: The Dutch government has nothing in particular to hide about New Guinea. I also know the country a little; have been there! The natives are very troublesome, addicted to head hunting and to putting people in their soup. It is a hard country to handle: impenetrable jungle, very rough, every village perched on its ridge at war with the one on the next ridge. It is very dangerous for whites, unless they know how to get on with the papocas. They are really not as bad as reported; the worst have become so because their appreciation of the white man is based on acquaintance with such amiable specimens as usually visit the jungle, in search of birds of paradise or something. They really cannot be appreciated socially, but have certain qualities when properly cooked;—good seasoning soaked into them long and strongly; whisky gives a good flavor to their stew. The Dutch government wants to get the country tamed in its own way, slowly. It does not want an oil boom or Australian drillers to civilize its papocas. I think it is a good policy. The oil can wait for a while, if there is any. The drillers would only get into trouble, be eaten and head-hunted, and the Government would get the blame. If they wait half a generation, matters will be all right.

BIBLIOGRAPHY OF REFERENCES

I. "British Expedition in Dutch New Guinea," *Geographical Journal*, XXXVIII (1911), No. 3.

II. A. F. R. Wollaston, *Pygmies and Papuans*, 1912.

III. J. E. Carne, "Notes on the Occurrence of Coal, Petroleum, and Copper in Papua," *Dept. of External Affairs Bull. No. 1* (Melbourne, 1913).

IV. E. R. Stanley, "The Papuan Petroleum Area," *Report of the Australasian Association for the Advancement of Science*, Vol. XIV (Melbourne, 1913).

V. A. Wade, "Petroleum in Papua," *Commonwealth of Australia, Parliamentary Paper* (Melbourne, 1914).

VI. T. W. Edgeworth David, "The Geology of the Commonwealth," *Federal Handbook on Australia* (Melbourne: British Association for the Advancement of Science, 1914).

VII. F. Chapman and A. Wade, "A Collection of Cainozoic Fossils from the Oilfields of Papua, with Geological Introduction," *Home and Territories Department Bull. No. 5* (Melbourne, 1918).

VIII. J. Read and M. M. Williams, "Note on a Papuan Natural Petroleum." *Journal of the Society of Chemical Industry, Sydney Section*, Vol. XXXVIII (1919), pp. 319–320.

IX. J. Read and A. C. P. Andrews, "Note of a Papuan Natural Petroleum, Part II," *Journal of the Society of Chemical Industry, Sydney Section*, Vol. XXIX (1920), pp. 289–91.

X. E. R. Stanley, "A Contribution to the Geology of New Guinea," *Home and Territories Department, Bull. No. 7*, (Melbourne, 1921).

XI. ———, "The Geology of Papua," *Commonwealth of Australia* (Melbourne, 1923).

XII. ———, "Report on the Salient Geological Features and Natural Resources of the

New Guinea Territory," *Commonwealth of Australia, Parliamentary Paper No. 18* (Melbourne, 1923).

XIII. A. Wade, "Petroleum Prospects, Kimberley Division of Western Australia and the Northern Territory," *Commonwealth of Australia, Parliamentary Paper* (Melbourne, 1924).

XIV. H. A. Brouwer, *The Geology of the Netherlands East Indies* (New York: Macmillan, 1925).

XV. Lorentz Wichmann and Herderschee Franssen, *Nova Guinea: Résultats de l'expedition scientifique nearlandaise à la Nouvelle-Guinée en 1903, 1907, 1909, 1912 et 1913.*

TECTONICS OF THE MARACAIBO BASIN, VENEZUELA[1]

R. A. LIDDLE
The Pure Oil Company, Mexia, Texas

ABSTRACT

Ancient land masses of northern South America and the Caribbean Sea region have had an important influence on the position and shape of the Maracaibo Basin in northwestern Venezuela. Gondwana and Antillia, the two major land masses involved, lie southeast and northwest, respectively, of the basin. Minor land masses of the Venezuelan Andes, Sierra de Perijá, and Island of Toas are located on the south, west, and north edges of the basin, and have a close structural relation to secondary folding. Maracaibo Basin is a flask-shaped structural geosyncline 150 miles long, is flanked on the east, south, and west by high mountains, and is connected by a narrow neck with the Caribbean Sea on the north. Igneous, metamorphic, and sedimentary rocks within the basin range in age from at least Ordovician to Recent. Acidic and basic dikes and batholiths cut igneous and metamorphic rock. In places, sediments are intruded. Structural influence of igneous intrusions on surrounding rocks is believed to be negligible. *En echelon* arrangement of structures in Maracaibo Basin is suggested. The more highly inclined flank of the folds is generally toward the axis of the basin. Marginal faults locally are present, but are considered to be incidental to folding. Rotational movement of orogenic forces in the basin is suggested by a northward plunge of structures west of the lake, and a southward plunge of structures on the east side of the basin.

INTRODUCTION

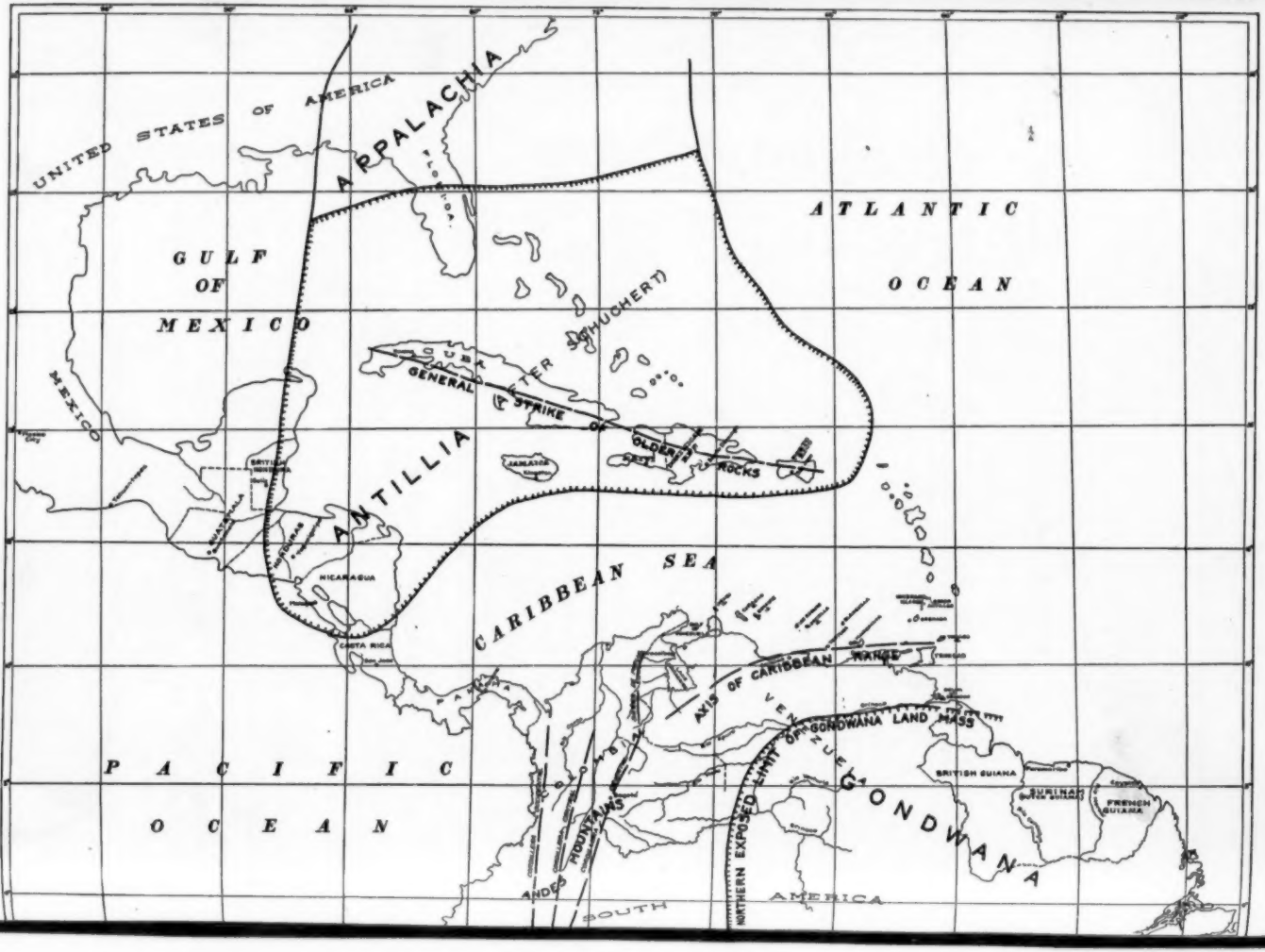
A discussion of the tectonics of the great basinal area of northwestern Venezuela should be prefaced by a brief consideration of the distribution of the ancient land masses of northern South America and the Caribbean Sea region (Fig. 1), as these resistant masses have determined the general position of the basin and the trend of the mountain ranges which delimit it.

Parts of two primary land masses of Archeozoic age are involved, the northwestern part of the Africano-Brazilian continent of Gondwana, and the southern part of Antillia.

Minor land masses, somewhat younger, though at least as old as Ordovician, occur in intermediate areas—in the Venezuelan Andes, Caribbean Range, Sierra de Perijá, on the Island of Toas, and as cores of the peninsulas of Goajira and Paraguana.

Metamorphic and sedimentary rocks, flanking these ancient gneissoid and granitic masses, range in age from Ordovician to Recent. In Maracaibo Lake Basin several thousand feet, chiefly of sediments—the metamorphics of western Venezuela are practically confined to the Venezuelan Andes area—dip steeply basinward on the flanks of the ranges, but flatten rapidly toward the center of the great geosyncline. Structural features likewise decrease in intensity outward from the mountains.

[1] This paper read before the Association by Fred H. Kay at the New York Meeting, November 15, 1926.


UNITED STATES OF AMERICA
APPALACHIA
ATLANTIC
OCEAN
GULF
OF
MEXICO
MEXICO
GENERAL STRIKE OF OLDHAM
ROCKS
ANTILLIA
CARIBBEAN SEA
NICARAGUA
COSTA RICA
PANAMA
AXIS OF CARIBBEAN RANGE
GONDWANA LAND MASS
PACIFIC
OCEAN
ANDES MOUNTAINS
NORTHERN EXPOSED LIMIT OF GONDWANA
BRITISH GUIANA
SURINAM
FRENCH GUIANA
GONDWANA
SOUTH AMERICA

DISTRIBUTION AND STRUCTURAL INFLUENCE OF MAJOR LAND MASSES

GONDWANA LAND MASS

The visible northwestern extension of the great Archean complex of eastern South America forms the floor of the Guayana Highlands, and is delineated quite accurately by the Orinoco River below its confluence with the Meta. How far north of the present course of the lower Orinoco these basement rocks extend beneath the broad inland plains is not known. They appear at the surface only a few hundred yards north of the river. It is quite evident that the river is working southward, and at its present level may have encroached several miles upon them. This southward migration is possibly influenced by the gradual uplift of the north coast of Venezuela. There are no data to indicate but that the encroachment has been uniform, and that the actual northern edge of the complex conforms closely in outline to the present exposed limit.

Conceding the actual northern limit of the Gondwana land mass to approximate in outline the present exposed northern edge, a remarkable reflection of this limit is apparent in the arcuate mountain chain composed of the Venezuelan Andes and their eastward extension—the Caribbean or Coast Range—which lie about 125 miles to the north. These mountains, which are a northeastward spur of the main Andean chain, swing in a broad arc conforming to the northern edge of the ancient continent of Gondwana against which thrusts from the north were exerted.

The Caribbean Range, considered as a great anticlinorium, is asymmetrical, with the more highly inclined flank to the north toward the source of the orogenic movements. It is difficult to observe this over the range as a unit, for much of the north flank lies buried in the Caribbean Sea; but individual folds within the mountain paralleling the main axis have greater inclination of their north flank.

In the Falcón region mountain ranges and local folds on the north flank of the Caribbean Range and subsidiary to it are generally asymmetrical, with the steep flank toward the Caribbean Sea.

ANTILLIA LAND MASS

On the islands of Cuba, Santo Domingo, Porto Rico, and Piñas, which occupy a part of the general area of the ancient continent of Antillia, there is a decided northwest-southeast strike in the older rocks. In fact, this strike coincides in alignment with the major axes of the islands. A reflection of this strike is found to the south in the position of the islands of Curaçao and Aruba; in the northwest-southeast folding on the peninsulas of Paraguana and Goajira; and in a similar strike of structural features between Manatiales and the Island of Toas. The northwest-southeast folding of northwestern Venezuela is in distinct contrast with structural disturbances to the south and is related to the folding of Antillia, which nowhere else has been observed to affect the country.

GEOGRAPHIC POSITION OF MARACAIBO BASIN

The main Andean chain, which forms a rugged backbone along the western coast of South America, has a general north-south trend. In Colombia this moun-

tain system splits into three separate ranges—the eastern or Cordillera Oriental constituting the boundary between Venezuela and Colombia. From this eastern range a northeast-trending spur leaves the main mass in the *paramo* of Pamplona, in the extreme southwestern part of Venezuela, and trending through the states of Táchira, Merida, and Trujillo, comprises the Venezuelan Andes and their eastern extension, the Caribbean Range. Maracaibo Basin occupies a great topographic basin and structural geosyncline between the Cordillera Oriental—Sierra de Perijá of Venezuela—on the west, the Venezuelan Andes on the south, and the *serranias* of Trujillo and Ciruma, an offshoot of the Venezuelan Andes, on the east. About 60,000 square kilometers of territory between these mountains is included in Maracaibo Basin, the center of which is occupied by Lake Maracaibo, a shallow body of brackish water approximately 12,000 square kilometers in extent, and directly connected on the north by a narrow neck with the Caribbean Sea.

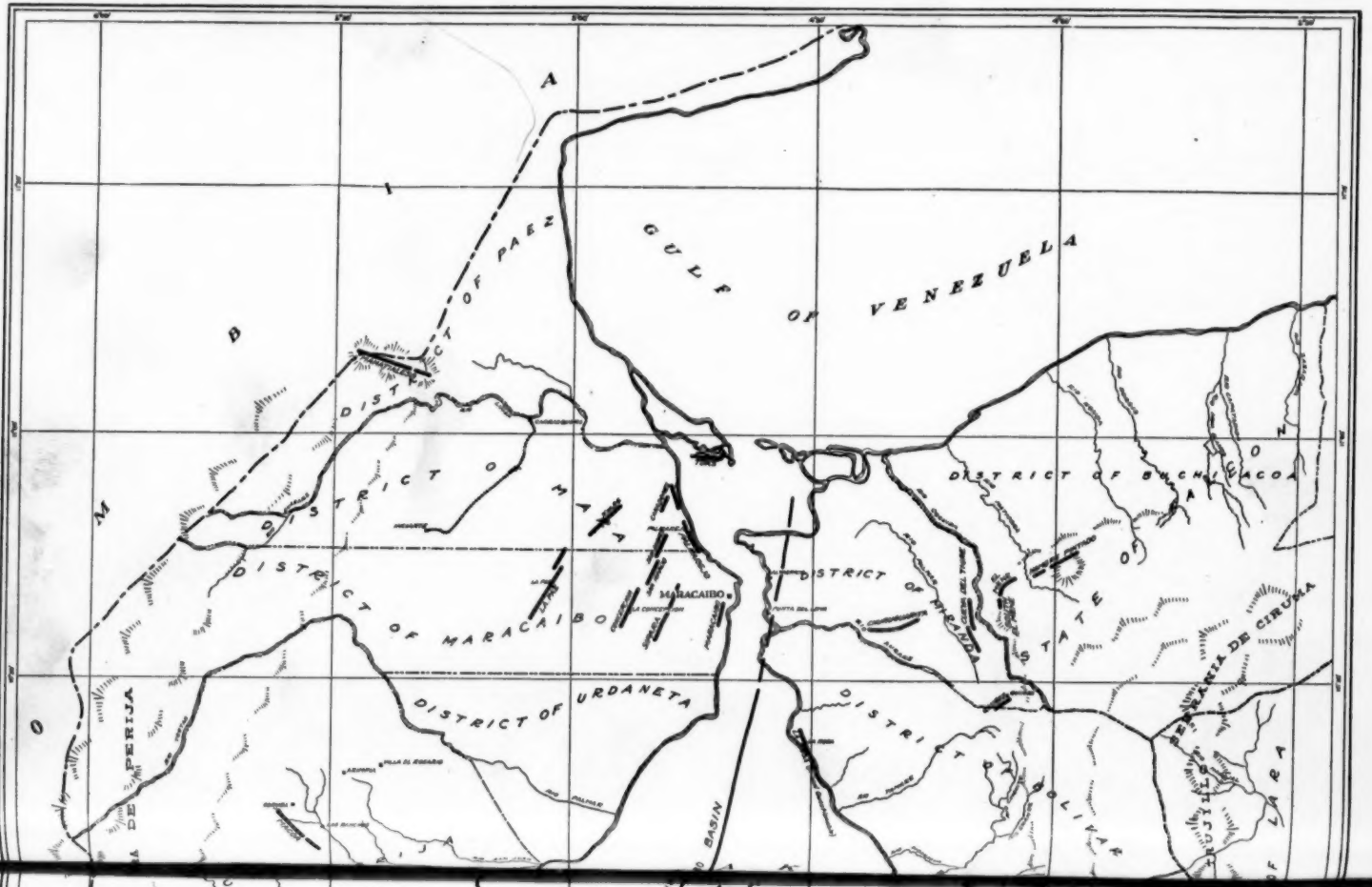
LAND MASSES OF THE MARACAIBO BASIN PROVINCE

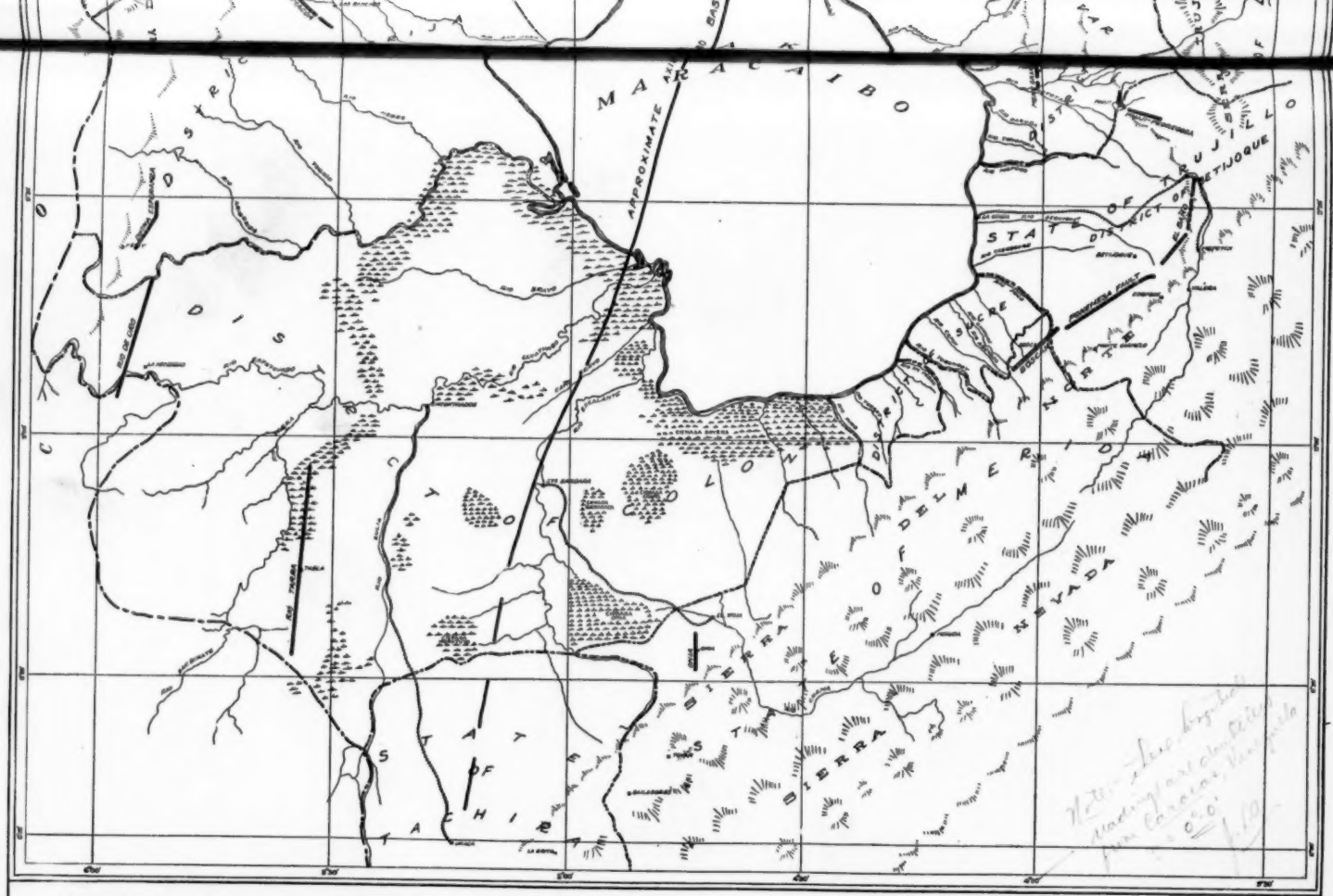
In the Venezuelan Andes, which flank the south and southeastern sides of Maracaibo Basin, and in the Sierra de Perijá on the west, are old land masses which compared with Gondwana and Antillia are merely local features of limited extent, but which have had an important influence in determining the outline of the basin. These land areas are at least as old as Ordovician; they are probably pre-Paleozoic. At the north end of the basin, in the present narrow neck which connects it with the sea, there is exposed on the little Island of Toas the top of an old land area of unknown extent. Though the oldest exposed sedimentary rocks overlying the granite core are basal Cretaceous, it is thought to be as old as the Sierra de Perijá and Venezuelan Andes masses.

The trend of the Venezuelan Andes mass is northeast-southwest; that of the Sierra de Perijá mass slightly east of north; and that of the Island of Toas a few degrees north of west. The regional strike of sediments and of major structural features in the vicinity of any of these masses conforms to the trend of the exposed part of the mass, indicating that these ancient land areas have had some influence on stratigraphy and structure.

VENEZUELAN ANDES MASS

From the eastern part of the State of Táchira northeastward through the states of Merida and Trujillo, the Venezuelan Andes expose a granitic core flanked by highly inclined metamorphic and sedimentary rocks. A definite age has not yet been assigned to the granite. It is known to be older than the Devonian and may well be pre-Paleozoic. On account of its different physical character and lesser degree of alteration, the Andes mass is considered to be distinctly younger than the metamorphic gneissoid mass south of the Orinoco. There are, to be sure, localities of gneissoid granite in the Venezuelan Andes, which probably were formed when metamorphism of the overlying sediments occurred, but there is no suggestion of the complete alteration of the Gondwana gneisses. Locally the granite core of the Venezuelan Andes and the overlying schists, phyllites, and quartzites are cut by


GULF OF VENEZUELA
GULF OF PAEZ
DISTRICT OF MARACAIBO
DISTRICT OF URDANETA
DISTRICT OF PERIJA
DISTRICT OF MIRANDA
DISTRICT OF BOLIVAR
DISTRICT OF BUCHIVACOA
STATE OF FALCON
PENINSULA DE PARAGUANA
MARACAIBO
MARACAIBO BASIN



ARRANGEMENT OF IMPORTANT SECONDARY STRUCTURES IN MARACAIBO BASIN

pegmatite, basalt, and quartz intrusions generally in the form of dikes. Locally the feldspar crystals are from four to six inches in length, and some of the quartz crystals measure several feet in diameter. Faulting is evident in many places, but its magnitude is unknown.

SIERRA DE PERIJÁ MASS

A granite core of the Sierra de Perijá has been discovered on the Colombian frontier in the northwestern part of the District of Perijá. Because of the inaccessibility of the area and the hostility of the Indians the central mass has been reached only on Rio Cogollo, Rio Piche, and Rio Aponcito. To the east of the central mass, and exposed between Rio Gé and Inciarte, is a smaller land mass—often referred to as the Totumo mass—which is probably related to the main mass to the west. Its physical character and composition, however, are distinctly different from the larger body. The Totumo mass is a grano-diorite, which appears to become more basic toward the north, but the main mass to the west is distinctly a feldspar-quartz granite of uniform texture. The Totumo mass is intruded by augite-porphyry dikes, and is extensively faulted along its eastern edge. The main mass, which is locally overlain by a thick conglomerate of igneous blocks and boulders, is definitely older than Devonian, but no beds older than basal Cretaceous have been found in contact with the Totumo mass.

ISLAND OF TOAS MASS

At the northern end of Maracaibo Basin (Plate 3) the top of an old land area reaches the surface on the little Island of Toas. It is composed of biotite-hornblende granite and, similar to Totumo, the oldest exposed rocks resting on the granite are basal Cretaceous. Both the granite and Cretaceous are cut by basalt dikes. At the eastern end of the island a small batholithic knob of augite-porphyry stands 50 feet above water.

The structural trend of the entire island and the strike of major faulting is north of west, probably connecting with the folding and faulting of Manantiales in the District of Paez. It is probable that this old mass, now locally exposed, is part of a considerable body, which may once have formed a barrier across the northern end of the basin.

GENERAL STRUCTURE OF MARACAIBO BASIN

Structurally, Maracaibo Basin is a geosyncline 150 miles in diameter, flanked on the east, south, and west by high mountain ranges. On the north there may have been at some time a mountain barrier, as suggested by the Manantiales—Island of Toas line of folding, but this disturbance is the only indication of closure on this end. In the southwest corner of the basin, however, there is a low structural and topographic saddle—the Táchira watershed—in the western part of the State of Táchira, which separates the Venezuelan and Colombian Andes. Though this low divide stands about 2,000 feet above lake level, it was, until the close of the Eocene, an open waterway between Maracaibo Basin and the Orinoco Embayment. To the east and west of this narrow valley the Andes rise to elevations

ranging from 4,000 to 16,000 feet. The great lowland, dotted with lagoons, at the southwest side of the lake, reaching almost to the Táchira watershed, indicates that this territory has only lately been reclaimed from the lake, which until very recently was about twice its present size, extending as far south as the states of Merida and Táchira and as far west as Rio Tarra, in the District of Colon.

The general trend of structure in the Táchira watershed is nearly north and south, reflecting the structure of the Colombian Andes, which bound it on the west. To the east of the watershed the major structural trend is northeast, conforming to the Venezuelan Andes, with which it is closely connected.

The strike of the Sierra de Perijá is slightly east of north, conforming to the trend of the old rock mass which underlies it. The east flank of the mountains forms a regional monocline which constitutes the west side of Maracaibo Basin. Subsidiary folding, generally *en échelon*, on this eastward-dipping monocline, parallels the mountains.

In the extreme northwestern part of the basin, a short distance north of Rio Guasare, there are interesting structural conditions at the junction of the northeast-southwest line of folding of Sierra de Perijá with a northwest-southeast line of folding reflected southward from Antillia. The northern end of the Sierra de Perijá, a few kilometers southwest of Manatiales, plunges steeply north into a zone of sharp folding and faulting, and a few kilometers to the north the same formations appear in a highly compressed southeast-northwest trending range of hills, striking toward the Island of Toas. In addition to this abrupt change in strike, a broad shallow syncline filled with coal-bearing Eocene sediments has been formed west of Inciarte.

On the east side of the lake there is a monocline dipping westward from the *serranias* of Trujillo and Ciruma. It, too, is interrupted by local structures with axes roughly parallel to the mountains.

This north-south folding continues northward approximately to the southeastern part of the District of Miranda, where between Quiros and El Mene, in the adjoining District of Buchivacoa, there is a change to a northeast line of folding, which continues through the greater part of the State of Falcón. This trend of folding is probably due both to the effect of the Antillean forces and those of the Caribbean Range to the south, the latter probably exerting the most marked influence.

MARGINAL FAULTS

Along the front of the mountains, which bound Maracaibo Basin on three sides, there is a narrow zone of intense faulting. This narrow, highly disturbed belt occurs at the lakeward edge of the foothills, paralleling them at different localities for several miles. There are, however, localities at which this faulting has not been observed, and it is possible that locally it does not exist. Where present it is generally characterized by the downfaulted side being lakeward, or on the side toward the regional syncline. Were the faulting more continuous, it would suggest that the synclinal basin of Lake Maracaibo occupies a great graben. In view of

the magnitude of the marginal ranges of anticlinal mountains which delimit the basin, it is apparent that the faulting is secondary—an adjustment incidental to the folding—and located along the border in a zone of intense stressing.

Along the east margin of the Sierra de Perijá from Inciarte southward at least to Machiques there is a narrow faulted zone of unknown displacement. At Totumo, in the northwestern part of the District of Perijá, there is faulting both at the eastern margin of the igneous mass and in the grano-diorite itself. Deep slickenside grooves are visible in the old mass in Quebrada Totumo. Southward toward Machiques the fault trends at a slight angle to the strike of the formations, causing them to wedge out toward the north against the old land mass. Part of this thinning of formations may be due to depositional conditions against the land area.

It is probable that the faulting along the eastern margin of the Sierra de Perijá dies out southward, for there is little evidence of any appreciable displacement in the southern part of the District of Perijá or in the District of Colon.

At the south end of Lake Maracaibo Basin, along the foot of the north flank of the Venezuelan Andes, there is extensive faulting, downthrown to the north or northwest. This generally occurs at the contact of the sediments with the old mountain mass on the south. A few kilometers north of this faulting are the Ponemesa and Valera faults, which are overthrust toward the mountains. The thrusting is indicated by a duplication of Eocene beds. From a superficial examination it appears that in general the mountain mass on the south has overridden the sedimentary and clastic deposits on the north, the zone of maximum displacement, as in the Sierra de Perijá, coinciding with the edge of the ancient rock mass.

On the eastern side of Maracaibo Basin there are no known igneous intrusions or old land areas in the *serranias* of Trujillo or Ciruma, but along the western margin of this mountainous region there is a marked fault with downthrow to the west. Not only is this faulting downthrown to the west, but in several rivers between Pauji and Cerro Luz, on the west flank of Serrania del Trujillo, especially Rio Raya, there is a distinct westward overturn accompanying the faulting. An analysis of the structure of the range indicates an overturned anticline with a faulted limb toward the lake and the major synclinal axis on the west. In this locality also the faulting appears to be secondary and incidental to the folding.

IGNEOUS INTRUSIONS

An inquiry into the origin and application of mountain-building forces which have effected prominent anticlinal ranges and subsidiary interior folds around Maracaibo Basin should give some consideration to igneous intrusions which are associated with them. The Venezuelan Andes, Sierra de Perijá, and Island of Toas masses are intruded by dikes and batholiths of both acidic and basic materials, which undoubtedly have had some effect on the associated rocks. A careful examination of these intrusions, however, suggests that they are resultant rather than causal. They appear to be dependent for origin and position upon other

orogenic forces. The restricted size of individual intrusions in comparison with the magnitude of the land masses and superimposed folds suggests that they have had no more than local effect—their presence and position being due to other mountain-forming forces which have disturbed and weakened or fractured the earth's crust. It is readily conceivable that batholiths of great extent can produce mountain ranges by simple uplift, but it has also been observed that igneous intrusions often have no effect either structurally or lithologically on sediments a few yards distant.

MINOR STRUCTURES

ARRANGEMENT AND TECTONIC SIGNIFICANCE

Observations have been made on the marginal masses and ranges, or major structural features, of the great geosynclinal basin of northwestern Venezuela. There remain for consideration the secondary folds, which occur generally *en échelon* between the foothills and the lake, especially on the east and west sides of the basin. On the south, swamps and Pleistocene and Recent mountain outwash conceal much of the area between the Venezuelan Andes and the lake.

Minor structures throughout the basin, with few exceptions, conform in trend to major disturbances. On the west side of the basin subsidiary folding on the east flank of Sierra de Perijá has an east-of-north to northeast trend—the general eastward swing in strike increasing toward the north both in the major and minor features. The average trend of Rio Tarra and Rio de Oro anticlines in the District of Colon at the southwest end of the basin is slightly east of north. In the southwestern part of the District of Perijá the Buena Esperanza anticline strikes more nearly northeast, if exception be made of an offset in the axis at the north end of the structure. In the northern part of the District of Perijá, Macoa nose, striking southeast-northwest, does not conform to the general structure. The north side is formed by steeply lakeward- or eastward-dipping Miocene beds, which conform in strike to the mountains on the west. The reverse side, which is weakly developed, has a southeast and south dip. Faulting in the foothills on Rio Cogollo, at the northwest end of Macoa nose, may be responsible for the erratic nature of the structure.

In the districts of Maracaibo and Mara the important structures at La Paz, Concepcion, Sipara, Kilometer 24, and a few intermediate anticlines strike about N. 45° E., roughly paralleling the mountain on the west. At the northern end of the District of Mara and in the District of Paez on the north, the effect of pressure from the north is evident in both major and minor structures. In the District of Paez the trend of structure is definitely north of west and south of east. A few kilometers to the south, in the northern part of the District of Mara, the influence of both the Sierra de Perijá and Antillia is indicated by domed structures and erratic structural trends.

In the area between Maracaibo and Mojáη, especially at Palmarejo, where Miocene structures protrude through Quaternary and Recent material, interesting structural conditions result from a combination of the movements which produced

the northeast-southwest trending folds on the south, and the northwest-southeast trending structural features on the north. In this intermediate area domal structures have been formed. They are a unique type of structure for this part of the country.

Excepting the erratic Macoa nose the following generalizations may be made for structures in the districts of Colon, Perijá, and Maracaibo: (1) their strike conforms to the trend of Sierra de Perijá; (2) their arrangement is generally *en échelon;* and (3) the steeper flank, in many places nearly vertical, is toward the lake and the geosynclinal axis.

On the east side of the basin not many structures are known, and the exact trend of an important one—La Rosa—has not been definitely determined. The Misoa–Mene Grande structure, which is a southward-plunging anticline, or nose, follows the general character of the folds of Maracaibo Basin. Its strike, slightly west of north, parallels the Serrania de Trujillo on the east and, like the *serrania*, its steeper flank is toward the lake and regional geosynclinal axis. The west flank is faulted and in a few places the fold is overturned toward the lake, suggesting that the faulting is incidental to the folding. Not enough structures are known on the east side of the lake to make possible generalizations concerning their arrangement.

At the southeast corner of the basin there is a decided swing in the strike of structures. This is exemplified by the trend of the axis of El Baño anticline. Its north end shows the predominance of influence of the Serrania de Trujillo, but the south end reflects the northward strike of the Venezuelan Andes. The strike of the latter is shown in the Mesa Grande or Boscan structure.

At the southwest end of the basin the north-south influence of the Venezuelan Andes is apparent as far east as Onia.

At the northeast end of the basin, in the vicinity of El Mene, there is a change from the north-south influence of the *serranias* of Trujillo and Ciruma to a strike ranging from N. 40° E. to N. 70° E., which persists throughout much of the Falcón region. El Mene structure plunges southwest, swinging toward the south at the western end. South El Mene structure, a few kilometers south of the west end of the main El Mene structure, trends north and south as do Cueva del Tigre and associated folds and the Misoa–Mene Grande nose, all of which reflect the structural influence of the mountains on the east. Southwest of El Mene, the Churuguarita structure indicates a continuation of the strike of the Falcón region.

CONCLUSION

This brief discussion has done little more than indicate some of the more important problems associated with a study of the tectonics of Maracaibo Basin. A few of the regional features have been mentioned, but a great mass of details is still lacking. Without these, generalizations and conclusions are little more than speculations.

Exception may be taken to the statement that the granite and grano-diorite

core of the Sierra de Perijá is primarily an old land mass, because of its position in what has apparently been a deep geosyncline in which thousands of feet of sediments ranging from Devonian to Eocene have been laid down. Though much of this igneous matter may be intrusive, an old pre-Devonian land mass is indicated by several hundred feet of igneous boulder conglomerate which locally overlies the igneous mass, separating it from the overlying Devonian sediments.

Between Escuque and Mesa Palmar, at the south end of Lake Maracaibo, thrusting of sediments toward the south onto older rocks may open to question the suggestion that faulting in the basin is ordinarily downthrown toward the geosynclinal axis. A majority of the known faults, however, are downthrown toward the axis of the basin.

A general *en échelon* arrangement of folds in the districts of Perijá and Maracaibo has been suggested. More detailed structural information is necessary before anything specific can be said regarding arrangement of structures on the south and east sides of the lakes. Especially is this true of the structurally complicated area lying between Maneta, Quiros, and El Mene.

The fact that most structures on the west side of Lake Maracaibo in the districts of Colon, Perijá, and Maracaibo plunge northward, though many on the east side of the lake plunge southward, suggests a rotational movement of orogenic forces. This movement, which seems to have been northward on the west side of the lake and southward on the east side, may have had some influence on the arrangement of *en échelon* structures. Observations to determine the existence of this rotational movement should give interesting results.

Maracaibo Basin affords a highly interesting, though complicated, field for the study of regional and local structure, stratigraphy, and paleontology, a study of which undoubtedly will lead to information of great scientific and economic importance.

SEDIMENTARY NATURAL GASES FROM THE OIL AND COAL FIELDS OF JAPAN, WITH SPECIAL REFERENCE TO THEIR GEOLOGIC OCCURRENCE[1]

K. UWATOKO[2]
2212 Channing Way, Berkeley, California

ABSTRACT

The paper is based on some of the results of an investigation of natural gas in Japan as conducted under the direction of the Aeronautical Research Institute of the Tokyo Imperial University. The author is concerned with the variation in chemical composition of natural gas with its modes of geologic occurrence. In general natural gases are classified as (1) those of igneous or inorganic origin and (2) those of sedimentary or organic origin. The natural gases from Quaternary formations contain mainly methane as the hydrocarbon compound, but the oil-bearing Tertiary formations contain not only methane, but also other hydrocarbon compounds. Some natural gases from the oil-bearing formations appear to show chemical variation with geologic conditions. Helium content of sedimentary natural gases from Quaternary and Tertiary formations is generally negligible. Several tables of chemical analysis accompany the paper.

INTRODUCTION

Of much interest in its bearing on fluctuation in the constitution of natural gas is the variation in chemical composition of natural gas with its modes of geologic occurrence.

A general investigation of natural gas of Japan was conducted under the general direction of the Aeronautical Research Institute of the Tokyo Imperial University. The important part of the data on which this paper is based consists of the chemical information, chiefly determinations of the constituents of natural gas, furnished by Messrs. N. Yamada, Y. Kanoh, and B. Yamaguti of the Research Institute. The author is mainly concerned in geologic research relating to the occurrence of natural gas. The field work on which the investigation and collection of natural gas was based was done from March, 1922, to September, 1925, by the author.

Under general consideration of the geologic occurrence and properties of natural gases the author classified the natural gases into two types: (1) the igneous natural gas which might have originated by inorganic action, containing volcanic gases and some hot and cold mineral spring gases; (2) the sedimentary natural gas which might have its origin in the sedimentary formations by organic action, the sediments containing organic natural gases from oil and coal fields and Quaternary formations.

The present paper includes a brief outline of the research on the relation of geologic occurrence to the chemical constitution of natural gas derived from the oil and coal fields of Japan.

[1] Manuscript received by the editor October 12, 1926.

[2] Assistant professor of geology, Hokkaido Imperial University, Sapporo, Japan. Introduced by L. C. Uren.

SAMPLING AND ANALYSIS

In the course of the investigation herein reported the gas sample was collected by replacement in water in a thick-walled glass container of about 800 cc. capacity. The bottle was then sealed carefully with a well-fitting rubber stopper. Hempel's standard method for the analysis of common constituents of natural gases and the condensation method of Cady and McFarland[1] for the determination of helium were both used.

GEOLOGIC OCCURRENCE OF NATURAL GASES

Natural gas is regarded as a gaseous mechanical mixture that issues from the earth; it has no fixed composition and exhibits a wide range in chemical character. Gas from one place should be expected to show some variation in its constituents with variation in the pressure of issuing gas. The natural gas herein described issues from the sands of Tertiary and Quaternary formations coming in contact with petroleum, coal, and water, so that the possible effect of this on the composition should be considered on the fluctuation in the hydrocarbon contents. The analyses, as far as the evidence goes, appear to show that the geologic formation in which gas is found has many influences on the composition. The characteristic and principal chemical constituents of the natural gas originally produced from the sedimentary formations of oil and coal fields are mainly hydrocarbon compounds.

NATURAL GASES IN THE QUATERNARY SEDIMENTS

In the following pages the author will endeavor to show that the composition of natural gas is decidedly altered by its associations, the composition of natural gases from Quaternary sediments being generally different from that of Tertiary natural gases. The characteristic and principal constituents of the Quaternary natural gas are shown in Table I. It will be noted that methane is the only hydrocarbon compound, probably "marsh gas."

Ethane and other higher hydrocarbons can hardly be observed in these samples, and the almost complete absence of higher hydrocarbons is striking, although nitrogen, carbon dioxide, and sulphur dioxide can be observed. The gas reservoirs, as determined from the logs of wells, are composed of loose sand and gravel and are capped by impervious clays showing simple horizontal stratification.

NATURAL GASES IN THE OIL-BEARING TERTIARY SEDIMENTS

The oil-bearing formations of Japan[2] belong to the Upper Tertiary period, probably Miocene and Pliocene, here classified into three divisions: the lower (Kubiki series), the middle (Siiya series), the upper (Nisiyama series). These formations rest unconformably on the coal-bearing formations of Eocene age and lie below the uppermost Tertiary strata containing lignite of Pliocene age.

The natural gases from the oil-bearing formation may generally be differentiated from those in the Quaternary sediments by the content of hydrocarbon

[1] H. P. Cady and D. F. McFarland, *Jour. Amer. Chem. Soc.*, Vol. 29 (1907).

[2] T. Iki, *Japanese Jour. Geol. Geog.*, Vol. 1 (1922), No. 1.

compounds, generally containing more of the higher hydrocarbons, as is shown in Table II.

Gases derived from different geologic horizons possess radically different chemical constitution, as is demonstrated in Tables II–VI.

RELATION OF HYDROCARBON CONTENT OF NATURAL GAS TO THE PROPERTIES OF THE ASSOCIATED CRUDE PETROLEUM

The gas, being in contact with oil at the bottom of the oil well, becomes saturated with vapor from the light constituent of the oil, the gasoline content being readily extracted by simple compression and cooling. It is generally a typical wet gas. Therefore the property of crude oil, being in contact with gas in the well, may control the fluctuation in the content of hydrocarbons of natural gas. The gas from the oil deposits in which light crude oil (30° to 52° Baumé) is produced con-

TABLE I

NATURAL GASES FROM THE QUATERNARY SEDIMENTS

Sample No.	Locality		Depth (in m.)	Date Sampled	Composition of Gas (Percentage)							
	Prefecture (Ken. Hu)	Field			CO_2 SH_2	Heavy Hydrocarbons	O_2	CO	CH_4	C_2H_6	N_2 Inert Gases	He
1..	Yamagata	Hunamati	95	Apr., 1922	5.71	0	0	0	87.57	0	6.70	0
2..	Yamagata	Nagasaki	76	Apr., 1922	10.92	0	0.32	0	84.45	0	4.31	0
3..	Yamagata	Kurazo	67	Apr., 1922	5.41	0	0	0	86.36	0	8.23	0
4..	Yamagata	Saigo	45.5	Apr., 1922	12.64	0	0.26	0	80.70	0	6.40	0
5..	Yamagata	Motodate	45.5	Apr., 1922	1.07	0	0	0	78.87	0	20.06	0
6..	Niigata	Ohkuti	308	Aug., 1922	0.63	0	0.18	0	93.21	0	5.98	0
7..	Nagano	Suwa	205	Oct., 1922	4.85	0	1.33	0.21	78.00	0	14.71	0
8..	Hukui	Torihama	30	Oct., 1922	8.15	0	0.10	0.17	81.27	0	10.31	0
9..	Siga	Ibe	78	Oct., 1922	3.51	0	0.18	0	75.21	0	21.10	0.017
10..	Siga	Maibara	47	Oct., 1922	1.12	0	0.14	0	73.09	0	25.65	0.017
11..	Tokyo	Haneda	.....	Sept., 1922	2.16	0	0.17	0	94.39	0	3.28	0
12..	Kagoshima	Sikine	40	June, 1922	5.05	0	0.10	0	75.17	0	19.68	Trace
13..	Siduoka	Yaidu	106	Dec., 1923	1.27	0	0.54	0	92.07	0	6.12	0.004
14..	Siduoka	Higasimatu-mura	126	Dec., 1923	0.47	0.03	0.21	0	93.58	0	5.71	0.007

tains much more of the heavy hydrocarbons (Table II) than that from oil deposits in which heavy crude oil (11° to 30° Baumé) is produced (Tables IV, V). The latter contains mainly methane and shows an almost complete absence of higher hydrocarbons.

Figure 1 shows the relation between the density of crude oil and the ratio of higher hydrocarbons to total hydrocarbons. It may be said that the natural gases containing a large quantity of higher hydrocarbons are associated with light crude oil, and that those containing a small quantity of higher hydrocarbons are associated with heavy crude oil, although no definite quantitative relation between the two can be observed.

RELATION OF HYDROCARBON CONTENT OF NATURAL GAS TO THE HORIZON OF THE OIL-BEARING FORMATION

The oil-bearing formations of Japan are classified in three divisions, as previously stated. The natural gas from the oil deposits of the upper oil horizons—Nisiyama and Siiya series, the former composed of mainly massive shale, the latter

TABLE II

Natural Gases from the Oil-Bearing Tertiary Sediments

Sample No.	Locality		Depth (in m.)	Date Sampled	Composition of Gas (Percentage)							Formation of Gas Sand
	Prefecture (Ken. Hu)	Field			CO_2 SH_2	Heavy Hydro-carbons	O_2	CO	CH_4	C_2H_6	N_2 Inert Gases	He	
1.....	Niigata	Iwagami	287–414	Aug., 1922	0.33	5.40	0.16	0.26	58.99	34.86	0	Trace	Kubiki series
2.....	Niigata	Nagamine	1,000	Aug., 1922	0	1.84	0.22	0.41	78.91	18.60	0	.....	Kubiki series
3.....	Niigata	Nagamine	1,045–1,170	Aug., 1922	0.15	1.64	0.12	0	79.64	17.37	0.72	.....	Kubiki series
4.....	Niigata	Nagamine	.....	Aug., 1922	0.38	1.68	0.23	0.28	79.27	18.16	0	0	Kubiki series
5.....	Niigata	Usirodani	900	Aug., 1922	0.63	1.35	4.51	0.21	45.22	30.48	17.60	0	Kubiki series
6.....	Niigata	Usirodani	920	Aug., 1922	0.51	7.11	1.71	0.38	37.71	49.89	2.69	.....	Kubiki series
7.....	Niigata	Hassaki	.....	Aug., 1922	4.10	0.39	0.09	0.40	92.69	1.35	0.71	0	Kubiki series
8.....	Niigata	Amaze	308–1,030	Aug., 1922	4.05	1.09	4.38	0.20	65.91	6.28	18.09	Trace	Kubiki series
9.....	Niigata	Omo	920	Aug., 1922	1.91	7.31	0.19	0.43	74.01	16.15	0	.....	Kubiki series
10.....	Niigata	Omo	910	Aug., 1922	6.18	8.45	0.18	0.09	42.04	9.24	33.82	Trace	Kubiki series
11.....	Niigata	Urase	590	Aug., 1922	0.11	12.43	0.10	0	79.00	6.99	1.37	Trace	Kubiki series
12.....	Niigata	Urase	340	Aug., 1922	0.79	2.49	0.12	0.30	86.40	9.90	0	Trace	Siiya series
13.....	Akita	Katurane	218–1,120	Aug., 1922	0.21	3.34	2.99	0	47.89	24.55	19.02	0	Kubiki and Siiya series
14.....	Akita	Katurane	1,020	Aug., 1922	0.25	1.20	12.58	0	24.39	12.49	49.09	.....	Kubiki series
15.....	Akita	Hanegawa	176–516	Apr., 1923	2.62	7.01	0.27	0.23	80.88	6.51	2.48	0	Kubiki series
16.....	Akita	Utimitikawa	137	Aug., 1922	11.46	1.57	0.28	0.04	82.17	4.48	0	.....	Kubiki series
17.....	Akita	Utimitikawa	133–147	Aug., 1922	12.97	1.51	1.22	0	76.45	4.20	3.83	0	Kubiki series
18.....	Akita	Katte	152–547	Apr., 1923	0.43	13.31	0.33	0.16	74.91	9.32	1.54	0	Kubiki series
19.....	Akita	Asahigawa	473–632	Apr., 1923	19.45	1.66	0.11	0.14	64.48	11.17	2.99	0	Kubiki series
20.....	Akita	Toyokawa	360–450	Apr., 1923	14.74	0.35	1.77	0.26	75.10	3.59	4.28	0	Kubiki series
21.....	Siduoka	Sagara	280–400	Oct., 1922	1.05	3.82	0.82	0.20	59.95	3.16	38.36	0.002	Megami series, equivalent of the Kubiki series
22.....	Simane	Higasi-mura	Natural outflow	Oct., 1922	0.25	0.54	0.31	0.14	92.62	4.59	1.55	0.002	Black shale series
23.....	Hokkaido	Ishikari	648	July, 1924	Trace	2.95	0.08	0	37.96	58.48	0.53	0	Black shale series, equivalent of the Kubiki series
24.....	Hokkaido	Ishikari	530	July, 1924	0.12	3.34	0.19	0	34.14	58.47	3.74	0	Black shale series, equivalent of the Kubiki series
25.....	Hokkaido	Ishikari	614	July, 1924	0.47	2.60	1.47	0	11.19	83.45	0.82	Trace	Black shale series, equivalent of the Kubiki series
26.....	Formosa	Rokudyukei	.....	Nov., 1924	0.96	0.21	0	0.04	94.32	1.35	3.10	0.006	Kohryukei series
27.....	Formosa	Rokudyukei	Natural outflow	Nov., 1924	1.74	0.42	0.17	0.04	93.05	2.70	1.88	0.002	Kohryukei series
28.....	Formosa	Tohsikyaku	Natural outflow	Nov., 1924	1.70	0.46	0.05	0.08	92.96	1.26	2.49	0.002	Kohryukei series
29.....	Formosa	Shukkoko	.....	Nov., 1924	30.57	1.37	0.12	0.12	60.15	3.92	3.75	0.002	Kohryukei series
30.....	Formosa	Shukkoko	632	Nov., 1924	31.97	0.54	0.06	0.10	61.53	2.57	3.23	0.006	Kohryukei series
31.....	Formosa	Kinsui	520	Nov., 1924	0.91	0.15	0.22	0.13	96.83	0	17.6	0.004	Kinsui series
32.....	Formosa	Kinsui	818	Nov., 1924	0.57	0.49	0.14	0.08	90.25	4.16	4.31	0.006	Kohryukei series
33.....	Formosa	Senshuryo	Natural outflow	Nov., 1924	1.04	0.26	0.11	0	95.80	1.25	1.54	0.005	Kohryukei series

composed of an alternation of sandy shale and sand—contains mainly methane as the hydrocarbon compound, as shown in Table IV.

But the natural gas from the Kubiki series, which is composed of black shale and tuffaceous sand, stratigraphically lower than the other two, may contain higher hydrocarbons (Table II). It appears to show a definite variation in chemical constitution of natural gas with the variation in horizon of sand from which it is derived.

It is also said that the crude oil from the Kubiki series is generally lighter in specific gravity than those from the Nisiyama and Siiya series;[1] therefore, the Kubiki series may produce light crude oil (30° to 53° Baumé), with heavy hydrocarbons in the gas.

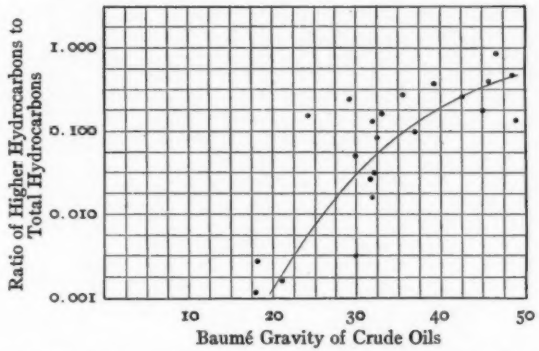


FIG. 1.—Relation between the density of crude oil and the ratio of higher hydrocarbons to total hydrocarbons.

It is remarkable that, at localities where it is found near the surface, there is a general tendency for natural gas from the Kubiki series to be richer in heavy hydrocarbons than natural gas from the Nisiyama and Siiya series.

There is also a tendency for natural gas from deeply buried parts of a productive sand to be richer in heavy hydrocarbons than natural gas from the same sand at localities where it approaches closer to the surface, as is shown in samples 17 and 18 of Table II.

G. A. Burrell and G. G. Oberfell[2] also pointed out that in one gas sand methane was the only combustible constituent, and in another sand a few hundred feet deeper the gas may contain other members of the paraffin series in the same locality. The present author has also found this to be true, as is shown by the analyses in Table III.

[1] T. Iki, *Jour. Faculty of Science* (Tokyo Imperial University), Sec. 2, Vol. 1 (1925); K. Uwatoko, *Japanese Jour. Geol. Geog.*, Vol. 3 (1924), No. 3.

[2] G. A. Burrell and G. G. Oberfell, *U. S. Bur. of Mines Techn. Paper 109* (1915); G. A. Burrell and G. G. Overfell, *Jour. Ind. Eng. Chem.*, Vol. 7 (1915).

In Table IV, the gases from the Kohryukei series[1] and Kubiki series, deeper beds, contain larger quantities of higher hydrocarbons than those of the Kinsui and Siiya series. In this case it must be also noted that the upper gases contain larger quantities of oxygen compounds than those of the lower gases, showing the oxidation of the natural gases in the upper beds.

HYDROCARBON CONTENT OF THE NATURAL GASES FROM OIL DEPOSITS INTRUDED BY VOLCANIC ROCKS

Some oil deposits of Japan, particularly the Akita oil field, are in contact with volcanic rocks. They include both extrusive and intrusive rocks, consisting mainly of dolerite, andesite, dacite, liparite, and breccia.

All natural gases produced from such oil deposits contain methane as the predominating hydrocarbon compound, with an almost total absence of higher hydrocarbons. This is a striking feature when compared with ordinary wet petroleum natural gas, as is shown by Table V.

TABLE III

Constituents	Kinsui Oil Field, Formosa		Urase Oil Field, Niigata	
	Kinsui Series (Depth, 520 m.)	Kohryukei Series (Depth, 818 m.)	Siiya Series (Depth, 340 m.)	Kubiki Series (Depth, 590 m.)
CO_2 and SH_2	0.91	0.59	0.79	0.11
Heavy hydrocarbons	0.15	0.49	2.49	12.49
O_2	0.22	0.14	0.12	0.10
CO	0.13	0.08	0.30	0
CH_4	96.83	90.25	86.40	79.00
C_2H_4	0	4.16	9.90	6.99
N_2				
Inert gases	17.60	4.31	0	1.37
He	0.004	0.006	Trace	Trace

It is also said that the crude oil produced from those oil deposits is generally heavy in specific gravity, ranging from 11° to 25° Baumé;[2] therefore, the oil deposits in contact with volcanic rocks may produce heavy crude oils with light hydrocarbon gases.

If a common origin for the natural hydrocarbons in the oil deposit of the fields be assumed, the intrusion of volcanic rocks may be one of the important factors which has caused the fluctuation in chemical constitution of gas in the deposit, possibly as a result of thermal decomposition.[3]

RELATION OF HYDROGEN-SULPHIDE CONTENT OF NATURAL GAS TO GEOLOGIC OCCURRENCE

Although the hydrogen sulphide content of the natural gas herein described is shown to be in admixture with carbon dioxide, it may as a rule be said that the oil

[1] I. Ohmura, *Petroleum Times* (Japanese), April, 1926.

[2] T. Iki, *Jour. Faculty of Science* (Tokyo Imperial University), Sec. 2, Vol. 1 (1925).

[3] Coward Bone, *Jour. Chem. Soc.*, Vol. 98 (1908).

TABLE IV

NATURAL GASES FROM THE UPPER OIL-BEARING TERTIARY SEDIMENTS

SAMPLE No.	LOCALITY		DEPTH (IN M.)	DATE SAMPLED	COMPOSITION OF GAS (PERCENTAGE)								FORMATION OF GAS SAND
	Perfecture (Ken. Hu)	Field			CO_2 SH_2	Heavy Hydro-carbons	O_2	CO	CH_4	C_2H_6	N_2 Inert Gases	He	
1.....	Niigata	Nanukaiti	360	Aug., 1922	1.61	0	0.17	0.20	97.47	0	0.55	Trace	Nisiyama series
2.....	Niigata	Ohhirota	Natural outflow	Aug., 1922	0.83	0.14	0	0.26	96.14	0	2.63	Trace	Siiya series
3.....	Niigata	Mituke sinmati	905	Aug., 1922	0.77	0.35	0.26	0.18	90.76	0	7.68	0.002	Nisiyama series
4.....	Niigata	Odiya	18	Aug., 1922	1.20	0.20	0.15	0.24	90.30	0	7.91	0	Siiya series
5.....	Niigata	Kitanigoro	310	Aug., 1922	0.14	0	0.08	0.17	96.83	0	2.78	0.002	Siiya series

TABLE V

NATURAL GASES FROM THE OIL DEPOSITS INTRUDED BY VOLCANIC ROCKS

Sample No.	Locality		Depth (in m.)	Date Sampled	Composition of Gas (Percentage)							Volcanic Rocks	Formation of Gas Sand
	Prefecture (Ken. Hu)	Field			CO_2 SH_2	Heavy Hydrocarbons	O_2	CO	CH_4	C_2H_6	N_2 Inert Gases	He	
1....	Niigata	Koguti	327	Aug., 1922	15.66	0.33	0.17	0.16	78.53	0	5.15	0	Andesite	Nisiyama series
2....	Niigata	Asahi	228	Aug., 1922	6.09	0	0	0	93.15	0	0.72	0	Andesite	Nisiyama series
3....	Niigata	Kanadu	225	Aug., 1922	7.69	0.09	0.12	0.18	91.34	0	0.58	0	Andesite	Nisiyama series
4....	Akita	Tanaka	130	Aug., 1922	3.05	0	0.13	0.20	94.22	0	2.40	0	Dolerite	Siliceous shale in the Kubiki series
5....	Akita	Mitikawa	230	Aug., 1922	3.03	0	0.05	0.16	95.74	0	1.02	.....	Dolerite	Nisiyama series
6....	Akita	Mitikawa	218–236	Aug., 1922	3.53	0	0.23	0.11	94.85	0	1.28	0.002	Dolerite	Nisiyama series
7....	Akita	Kurokawa	473	Aug., 1922	2.04	0	0	0.23	96.39	0	1.34	.....	Dolerite	Nisiyama series
8....	Akita	Kurokawa	418–463	Aug., 1922	2.86	0.23	0.35	0.11	95.63	0	0.82	0.002	Dolerite	Nisiyama series
9....	Yamagata	Hukiura	218	June, 1922	9.62	0.20	2.97	0	52.98	0	34.23	0.009	Andesite	Siiya series
10....	Yamagata	Aburayama	910	Apr., 1922	10.98	0.43	0.36	0	88.02	0	0.21	0.003	Andesite	Kubiki series

TABLE VI

NATURAL GASES FROM THE COAL-BEARING TERTIARY SEDIMENTS

SAMPLE No.	LOCALITY		DEPTH (IN M.)	DATE SAMPLED	COMPOSITION OF GAS (PERCENTAGE)								FORMATION OF GAS SAND
	Prefecture (Ken. Hu)	Field			CO_2 SH_2	Heavy Hydro-carbons	O_2	CO	CH_4	C_2H_6	N_2 Inert Gases	He	
1.....	Hokkaido	Numagai	194	Aug., 1924	0.31	0	0.25	0	99.29	0	0.15	0	Ishikari series
2.....	Hokkaido	Yubari	268	Aug., 1924	0.27	0	0.21	0	96.10	0	3.42	0.007	Ishikari series
3.....	Hokkaido	Yubari	157	Aug., 1924	0.12	0.06	0.38	0	92.86	0	6.58	0.004	Ishikari series
4.....	Hokkaido	Yubari	Natural outflow	Aug., 1924	0.34	0.45	0.39	0	94.72	0	4.10	0	Ishikari series
5.....	Hukuoka	Miike	16	June, 1924	2.56	0	1.00	0	66.61	0	29.83	0	Miike coal bed
6.....	Miyazaki	Utiumi	Natural outflow	June, 1924	0.55	0	0.17	0.20	94.60	0	4.48	0	Utiumi series

deposits in contact with volcanic rocks, or with rocks producing hot mineral water, contain a relatively large percentage of hydrogen sulphide. The latter is considered to be of igneous origin, but the presence of much hydrogen sulphide is not always an indication of the proximity of volcanic rocks and hot mineral waters.

NATURAL GASES IN THE COAL-BEARING TERTIARY SEDIMENTS

The coal-bearing formations of Japan belong to the lower Tertiary period, probably Eocene.[1] Natural gases herein described were collected at the Isikari and Miike coal fields.

The natural gases from the coal-bearing Tertiary formations show some differences in chemical constitution when compared with those wet natural gases from oil deposits; the former contain methane only as the combustible hydrocarbon (Table VI), and the latter contain methane, ethane, and higher hydrocarbons (Table II).

HELIUM CONTENT OF SEDIMENTARY NATURAL GASES

Generally speaking, most natural gases, as far as the analyses in the foregoing tables show, contain a negligible quantity of helium, although in some gases a small quantity may be observed.

Extensive investigations on helium-bearing gases in the United States[2] and Canada[3] showed that the geologic age may be one of the important factors in finding the formation from which helium-bearing natural gases issued. The practical absence, therefore, of helium in sedimentary natural gases from the Quaternary and Tertiary oil and coal formations may be expected from the geologic age of the gas sands.

Although helium content of natural gases from younger sedimentary formations is relatively small, it may be said that gases of thermal value, high in nitrogen, usually have a higher helium content than those having a lower nitrogen percentage. The presence of much nitrogen, however, is not always an indication of helium.

The natural gases from oil deposits in contact with volcanic rocks may contain a larger quantity of helium than those not in contact with volcanic rocks. This may mean that the igneous natural gases contain a larger quantity of helium than those of the younger sedimentary natural gases, although the presence of the volcanic rocks in association with the oil deposits and the hot mineral waters in the oil wells is not always an indication of helium.

McLennan,[4] in his report of the investigation of natural gases in Canada, stated that no definite relation between helium and other substances responsible for radioactive emanations can be observed. In the present case it is also impossible

[1] H. Imai, "Study on the Coal-Bearing Tertiary Formations in the Isikari Coal Field," *Geographical Magazine* (Japanese), 1923.

[2] G. S. Rogers, *U. S. Geol. Survey*, p. 121 (1921).

[3] R. T. Elworthy, *Invest. Miner. Resour. & Min. Ind.*, No. 616 (Canada, 1923).

[4] J. C. McLennan, *Trans. Roy. Soc. of Canada*, Vol. 12 (1918).

to state any relation between them because of general absence of helium in the sedimentary natural gases from oil- and coal-bearing Tertiary formations.

CONCLUSION

The chemical composition of natural gases issuing from sedimentary Tertiary formations of the oil and coal fields of Japan may vary with mode of occurrence, although in the present paper only the content of hydrocarbons, hydrogen sulphide, and helium is discussed.

The natural gases from Quaternary formations contain mainly methane as the hydrocarbon compound, while those from oil-bearing Tertiary formations also contain mainly methane, but in addition, other hydrocarbon compounds.

Of these natural gases from oil-bearing formations, some appear to show variation in their chemical constituents with geologic conditions surrounding the oil and gas deposits.

Helium content of sedimentary natural gases from Tertiary and Quaternary formations is generally negligible, although igneous natural gases may contain large quantities of helium.

ACKNOWLEDGMENTS

For information concerning the chemical constituents of natural gases the writer is indebted to Messrs. N. Yamada, Y. Kanoh, and B. Yamaguti, of the Aeronautical Research Institute; and to Professor T. Iki, of the Tokyo Imperial University, for his constant sympathy and advice during the progress of the work.

The author gratefully acknowledges his indebtedness to Professor L. C. Uren, of the University of California, for suggestions and criticisms of the manuscript.

GEOLOGICAL NOTES

SCALE OF HARDNESS AND COHESION FOR SEDIMENTARY ROCKS

E. M. Kindle, of the Geological Survey of Canada, has proposed the following scale of hardness and cohesion for sedimentary rocks which is added to the scale for minerals (*Researches in Sedimentation in 1925–26* [Washington: National Research Council, 1926], pp. 95–97).

sapphire	9.	
topaz	8.	
quartz	7.	quartzite
orthoclase	6.	
apatite	5.	
fluorite	4.	certain varieties of dolomite limestone
calcite	3.	
rock salt	2.	
talc	1.	certain varieties of aeolean limestone
	.9	marlite
	.8	chalk
	.7	diatomite
	.6	
	.5	marine clay (Pleistocene, Ottawa valley)
	.4	
	.3	recent marl
	.2	
	.1	lake bottom mud
	.0	sand (dry)

ORIGIN OF FOLDING IN OKLAHOMA

R. W. Clark, consulting geologist at Okmulgee, Oklahoma, contributes the following report to the National Research Council on the origin of folding in Oklahoma: "The oil-bearing structures of Okmulgee County are not deformational structures, but are due to sedimentation; the topography of the pre-Wilcox was rather rugged; clastic sediments laid down on this uneven floor slid downhill filling the valleys. This accounts for greater shale intervals on the flanks and off structure areas. The filling-up process continued until the angle of repose put a stop to it, whereupon sedimentation continued in a normal manner. The greater thickness of shale on the flanks and in the valleys causes greater compression there due to overload, thus accounting for the slighter dips in the higher formations" (*Researches in Sedimentation in 1925–26*, p. 25).

REVIEWS AND NEW PUBLICATIONS

The Geology of the Island of Trinidad, B.W.I. By Gerald A. Waring, with Notes on Paleontology by G. D. Harris. The Johns Hopkins University Studies in Geology No. 7, 1926. $1.25.

The island of Trinidad began to receive the attention of geologists as early as 1858 with the work of Wall and Sawkins which furnished the groundwork for practically all subsequent geological studies. Since that time the intricate stratigraphic and structural problems of Trinidad and the very apparent possibilities of profit presented by its overlapping, folded, faulted, oil-stained beds have intrigued the interest of many geologists. Undoubtedly each attack by a competent man has added appreciably to the knowledge of the geology of the island and has served to some extent to improve the conclusions reached by predecessors, but the geology is so complex that each new worker always seems able to find much that the earlier workers overlooked. The work that is here reviewed is the most satisfactory presentation of the geology of Trinidad with which the reviewer is familiar. The author has utilized the best from the published work of other geologists and has also added much from his own and others' hitherto unpublished work. This report, however, compilation and summary though it is, must be considered merely a progress report—a step toward the final goal of complete understanding of the complex geology of this interesting and rich island.

This description of the geology of Trinidad has a significance outside of the island itself, for the westward-projecting capes at the northwest and southwest corners of the island point like fingers to related regions in Venezuela, the formations are known to be related, at least in part, to strata as far west as Colombia and Peru, and the major tectonic features must at some point and in some way affect the Venezuelan mainland. This is particularly true of the fault that must margin the island on the south.

STRATIGRAPHY

The exposed rocks of Trinidad are probably all of Mesozoic or Tertiary age, although Guppy believed he had evidence suggesting the Devonian age of some of the metamorphosed strata in the northern part of the island, and most of the other earlier writers classified them as "age unknown." Waring and Harris are inclined to place the Laventille limestone, which seemingly is the youngest of these altered sediments and igneous rocks, in the "early Mesozoic" on the basis of poorly preserved fossils.

The age of the exposed rocks becomes progressively younger toward the south, the general strike being a little north of east, and the general dip, modified by complex crumpling and faulting, being to the south. The relation of the old metamorphosed rocks in northern Trinidad to the unaltered sediments farther south will probably never be known, for there is a broad belt covered by Pleistocene and uppermost Pliocene strata just south of the northern highlands where the metamorphic rocks appear; but it seems probable that south of them there is a profound fault and that the oldest of the sediments exposed to the south are in fact some thousands of feet stratigraphically above the metamorphics.

Consideration of the constituents of the exposed Tertiary and Cretaceous formations, and deduction regarding their possible origin in the metamorphics of the Northern Range or in similar rocks would at least permit an inference regarding the relations of the metamorphics and the unmetamorphosed rocks, and it is hoped that the next comprehensive discussion of the stratigraphy of Trinidad will take up this point. Probably V. C. Illing, who has made exhaustive studies of the petrography of the sediments of central and southern Trinidad, could contribute to our knowledge on this point.

The Cretaceous of Trinidad is particularly interesting in that the youngest Cretaceous strata apparently are not represented on the mainland of South America. In fact Harris feels that the fauna obtained from a shred of Upper Cretaceous that appears on the west coast of the island "has a sufficient number of elements in common with the late Cretaceous of northern Africa to admit of fairly definite correlation." The older Cretaceous strata of Trinidad can be definitely correlated with those of Venezuela. Evidently either the strata corresponding to the uppermost Cretaceous of Trinidad have been eroded from such areas as have been studied in the mainland to the west, or they were never deposited there. Either alternative probably calls for more post-Cretaceous erosion in Venezuela than took place in Trinidad, although the small exposures of Trinidad may represent fault blocks that were preserved by deep burial.

The record of Tertiary sedimentation as given in this report shows that accumulation took place for the most part in shallow marine waters. The deposition was frequently interrupted by uplift and folding, but in spite of the fact that thousands of feet of strata have been removed by erosion there is strikingly little evidence, if we may judge from this report, of accumulation under continental conditions. It would suggest that after each period of folding, faulting, and exposure, the dominant erosion was by marine planation, rather than by streams, or at least that the final reworking of the sediments that terminated each period of uplift and subsequent planation was by the sea. Here again more evidence that will either support or negative the idea of very perfect planation is needed. It is true that the geologic map that accompanies the report strongly suggests overlap of some formations on a surface of rather high relief, but such overlap should be accompanied by sediments of a shore or near-shore type that are not mentioned in the formation descriptions. The Brasso conglomerate of upper middle Miocene age does indicate relief with consequent rapid erosion, transportation, and deposition, but it is apparently restricted to a narrow strip and probably never covered any large area. The problem is of course complicated by the fact that the sediments of Trinidad are in large part argillaceous rather than siliceous, and these, even under conditions that might develop high relief, would result in accumulations of clays and silts, rather than sands and conglomerates, so that it is apparent that recognition of near-shore types of sediments and continental deposits will not be simple. In this connection a study of the contact of the Red-weathering Clay with the underlying strata in the vicinity of the Oropuche Lagoon oil field and the Lamont oil field would be of interest. No unconformity at the base of the Red-weathering Clay is described in the text, but it seems to overlap successively on the Green Clay, the Upper Princes Town Marl and the Lower Princes Town Marl, if we may trust the distribution of formations shown on the geologic map. If this overlap is actual rather than merely apparent it would seem that the Red-weathering Clay must be either a product of recent erosion, or else in part a continental deposit, or else that the older beds were folded and tilted between Green Clay and Red-weathering Clay time.

STRUCTURE

The intricate folding and faulting that characterize the geologic structure of the island are impressed on one, both by the text of the report and by the geologic map and the cross-sections that accompany it. It would seem that there was thrusting both from the north and from the south so that the least deformed area is not one margin of the island, as would be the case if the thrust was all from a single direction, but rather an interior strip with closely folded and broken strata on either side of it. Even here there is some sharp folding. Part of the apparent difference in intensity of deformation undoubtedly is due to the age of the beds exposed, for there can be no doubt that there were many periods during which folding and faulting took place, and other things being equal, the areas where the oldest rocks are exposed would be most deformed.

Two distinct systems of faults are shown on the map that accompanies this report. The oldest has both normal and reverse faults which trend approximately N. 65° E. in sympathy with the general trend of the more pronounced folds. The second system is shown to be approximately perpendicular to the first, its faults are almost all normal, and in conjunction with the first system it breaks the southern half of the island into a multitude of long, narrow semirectangular blocks. Of course, it is recognized that it is not possible to even indicate all the known faults on a scale of 1:150,000, which is that of the map which accompanies this report, and it is highly improbable that all the fracturing on Trinidad will fall into these two systems. It is of interest, however, that these two definite systems are indicated, the one showing compression in a general north-south line, the other showing tension at right angles to the first movement, with further north-south compression that permitted horizontal movement along the fractures opened by the tensile stress.

GEOLOGIC HISTORY

The discussion of the geologic history seems worth summarizing in some detail. In so far as northern Trinidad is concerned, this discussion is limited to indorsement of Guppy's belief that the shoals and banks that extend seaward from the north coast indicate great downthrow to the north which dropped much of the original range into the sea, and that the transverse valleys of the northern range, which are progressively lower to the west until the westernmost ones are below sea-level, are along cross faults with progressively greater downthrow to the west. The first of these assumptions is both natural and reasonable, although it is still but an assumption. The second seems, to the reviewer, to be but a partial truth at best. There may be faults along the transverse valleys, and these faults may have progressively greater downthrow to the west, but they are valleys of erosion, and not recent rifts. The westernmost of these valleys of erosion are now drowned. This means a westward tilting of northern Trinidad after the valleys were formed. The tilting probably affected only the western part of the island, and might therefore preferably be spoken of as a warping which affected the eastern part of the island little if at all. This warping is also manifested in the Northern Lowland belt which shows much more extensive accumulations of swamp and stream material on the west than on the east side of the island. The evidence that the southern part of the island was affected by this warping is not conclusive, but very probably there was some gentle tilting at the time this last major structural adjustment of northern Trinidad took place.

In Trinidad, as in adjacent Venezuela, there was probably major uplift in late Upper Cretaceous or early Eocene time that brought the marine Cretaceous beds up out of the

sea and subjected them to erosion. This uplift was undoubtedly accompanied by some folding, although the reviewer does not believe it was accompanied by such intensive thrusting as was that of late Eocene or early Miocene time. The available evidence for Trinidad is not conclusive, but this uplift probably affected the entire island.

The eroded Cretaceous surface was at least partially covered by sediments of Eocene age, most of which were apparently laid down in shallow but marine waters; but during Eocene time there was further uplift and folding. Nothing is said by the authors about the intensity of this Eocene folding, but the reviewer is inclined to believe that this was one of the most severe of the periods of deformation that have affected northern South America, and that the thrusting during this period was responsible for no small part of the metamorphism that has affected the Cretaceous and some of the Eocene of Venezuela. If the Venezuela sediments that were deposited before this deformation occurred are contemporaneous with the lower Eocene beds of Trinidad, then the Misoa-Trujillo sandstone and the Pauji shale of western Venezuela may be homotaxic equivalents of the Marac formation of Trinidad.

It is quite possible that Trinidad was never entirely submerged during Eocene time, but during the Oligocene it evidently sank slowly and at the same time was warped so that much greater thicknesses of the Oligocene marls (Lower St. Croix) were deposited in the central part of the so-called "Marl Belt" than elsewhere. The nature of the sediments indicates that the sinking must have been oscillatory, now exceeding the rate of sedimentation, now lagging behind it; and at the close of the Oligocene the island, or at least those parts where the evidence is clear, was again exposed to erosive agencies. Waring mentions "a minor unconformity" between the Oligocene Lower St. Croix and the Miocene Upper St. Croix, but the distribution of formations as shown by the geologic map, with the Upper St. Croix in contact with Oligocene, Eocene, and even Cretaceous rocks in different places, would indicate that this was really a widespread and important unconformity, although not necessarily an angular one. Part of the irregularity may be explained by the assumption that Trinidad was not entirely submerged during Oligocene time and that the unconformity was essentially one of overlap, but it seems much more probable that at the close of Oligocene time there was emergence and appreciable erosion with some tilting.

ECONOMIC GEOLOGY

The discussion of the occurrence of oil is very brief. This is perfectly understandable and no criticism can attach to the authors for failure to present details of oil-field structure or to give their views concerning the dominating factors that control the existence of the oil pools, for the paper is published through the courtesy of the Whitehall Petroleum Corporation Ltd., by whom the senior author was employed during his stay in Trinidad, and naturally nothing could be published that might react to the disadvantage of the company.

We learn from the short discussion that the first well was drilled on the island about 1866, but nothing that appeared really important was developed before 1902. Since that time exploration has been intermittently carried on, and now there are about twenty "fields" that are yielding, or have yielded, oil, and many prospects where the existence of oil, albeit not in important quantity, has been demonstrated. All the real pools, with the exception of Tabaquite in the Central Range, get their oil from beds not older than lower middle Miocene, and like most Miocene oil it is heavy and asphaltic. The wells are for

the most part of small yield; but this general rule may be broken, for Well No. 7 of the Barrackpore oil field in the southeastern part of the island "was credited with a production of 470,000 barrels before it went dry in 1919," and there have been other wells that yielded in excess of 300,000. Now and then wells start to yield at a phenomenal rate, but these big wells almost invariably flow only for a few hours, or, at best, days, before they are choked by the fine flourlike sand that characterizes the Miocene oil measures.

The Tabaquite field is believed to obtain its oil from the Lower St. Croix formation of Oligocene age. This oil is much more desirable than that of the other fields, since it has a gravity of about 41° Baumé and some of it has a very appreciable paraffin content.

The influence of geology on oil exploration is well brought out by the locations of the prospect wells as shown on the map. A high percentage of them are located on well-defined anticlinal structure. This may be due in part to the more general occurrence of oil and gas seepages and mud volcanoes on such structure, but in part, at least, must be credited to geologic guidance. Every possibly oil-bearing formation, including the Cretaceous, has been tested by one or more wells so located that the structure is at least not unfavorable. Almost invariably some oil was found, but the number of tests that have been drilled without developing other fields like Tabaquite shows that these older formations must be regarded with much less favor than the richly oil-bearing middle and upper Miocene. In view of the complex structure and the numerous unconformities, however, it cannot be said that any of the unproductive anticlines have been decisively eliminated as potential oil fields.

The annual yield of the Trinidad fields has quite steadily increased, and has not been below 1,600,000 barrels since 1916. The American Petroleum Institute estimated 4,284,000 barrels for 1924. The yield in 1925, of 4,654,000 barrels, was the highest that has thus far been recorded, but it is to be anticipated that this yield will be far surpassed in the future when operating difficulties have been overcome.

K. C. HEALD

THE ASSOCIATION ROUND TABLE

THE 1926 PACIFIC SECTION MEETING

The third annual meeting of the Pacific Section of the Association convened in the Ballroom foyer of the Biltmore Hotel, Los Angeles, October 28 and 29.

Promptly at ten o'clock, the morning of the 28th, the meeting was called to order, and a welcome to visiting members and guests was extended by Chairman E. F. Davis. The day was given to presentation and discussion of the following technical papers, special attention being given to that by C. F. Tolman, of Stanford University.

Origin of California Oil.....C. F. TOLMAN
Geology of the West Mexican Islands.....G. D. HANNA
The Significance of Consequent Drainage in Recent Deformed Regions.....F. P. VICKERY
Notes on the Occurrence of Oil in Basalt in Western Washington.....F. S. HUDSON
Geology of the Northwestern Part of the Olympic Peninsula.....R. B. MORAN and R. H. PALMER
The Fernando Group of Southern California (Preliminary statement).....J. E. EATON

Following a short recess at three o'clock, a business meeting was held and the following officers were elected for the ensuing year: Henry J. Hawley of San Francisco, chairman, and Nicholas L. Taliaferro, of Berkeley, secretary-treasurer.

Friday's session was also presided over by Chairman Davis and the day devoted to technical discussion, the feature of the day's program being a general paper relating to the tectonics and paleogeography of California Coast Ranges by Bruce L. Clark, of the University of California.

Foraminiferal Section along Adams Canyon, Ventura County, California.....H. L. DRIVER
Some Generalizations Concerning the Tectonics of the Coast Ranges of California.....BRUCE L. CLARK
Heavy Mineral Correlation of Core Samples.....R. D. REED and J. P. BAILEY
The Microfaunas of the Uppermost Pliocene or Lowest Pleistocene in the Los Angeles Basin.....A. J. TIEJE
A Miocene Section of the San Juan District, California.....M. G. EDWARDS
Geological Observations along Southern End of San Joaquin Valley.....H. W. HOOTS
Some Notes on the Geology of the San Joaquin Valley....GERARD HENNY
Subsurface Lithology of the Pliocene of Los Angeles Basin..GEORGE R. ELLIOTT
Economic Spacing of Oil Fields.....R. B. PHELPS

An attractive luncheon was given the visiting ladies, by the Section, Friday, October 29, at the Mary-Louis tea-room, followed by a theater party at the Biltmore theater at a showing of *Ben Hur*. Friday evening members and guests gathered at Oakmont Country Club for a Hallowe'en dinner dance.

During the two days of the meeting one hundred members and fifty guests registered. Though the meeting adjourned Friday at five o'clock, the majority of visiting members remained over, and on Saturday afternoon, with local members, occupied a section at the football game of Stanford and the University of Southern California, a splendid ending to a most interesting and enjoyable meeting.

C. M. WAGNER

INTERNATIONAL GEOLOGICAL CONGRESS[1]

The meetings of the Congress as a whole took place in Madrid, May 24–31, 1926. It may be said at once that the Congress was a great success from whatever standpoint it may be regarded. The Spanish organization, which made all of the arrangements, could not have acted with better taste and with more industry to satisfy all of the desires of the delegates and members of the Congress. This is more meritorious when one considers that fifty-two different countries were represented.

The members attending numbered about one thousand, of whom four hundred came from Spain. Of the other principal countries, Germany was represented by 114, United States by 74, France 51, Russia 32, England 30, Belgium 30, Poland 21, Sweden 17, Hungary 16, Austria 15, Czechoslovakia 14, Italy 12, Netherlands 12, Switzerland 10, Rumania 9, and Portugal 8. The other countries represented were: Angola, Argentina, Australia, Brazil, Bulgaria, Colombia, Congo Belge, Gold Coast, Cuba, Chile, China, Denmark, Ecuador, Egypt, Estonia, Finland, Greece, Guatemala, East Indies, Japan, Letland, Morocco, Mexico, Norway, New Zealand, Nyassaland, Panama, Peru, Rhodesia, Sudan, Tunis, Turkey, South Africa, and Uruguay.

The official languages used were Spanish, English, French, and German. However, in social intercourse French was commonly used. The Congress added Italian and Russian as additional official languages for the next Congress. This question of languages will have to be solved somehow for future international scientific meetings. Many delegates spoke of it. Though in Europe nearly all educated men speak at least two languages, these were found not to be enough.

It would take too long to mention all of the courtesies shown us by our Spanish hosts. The outstanding feature was the reception at the Royal Palace, in Madrid. It was a beautiful sight to see the splendid gobelins, paintings, and chandeliers in the different rooms and corridors, the footmen dressed in medieval costumes; and the assemblage itself was gorgeous. All of the Congress members were more or less covered with decorations, orders, and medals. Most of our Spanish hosts and the entire diplomatic corps were in uniform. The only exceptions were the American members in plain evening dress, and just on that account they appeared the more distinguished.

Another beautiful function was the concert at the Apollo theater, also attended by the royal court. The program consisted of three parts: first, music by the Madrid symphonic orchestra; second, vocal concert by a grand chorus of male and female voices; and third, typical dances. With particularly good taste, all of the numbers were typically Spanish, in order to show the foreign members the spirit and ideals of Spain.

The concluding social feature in Madrid was a banquet and ball given by the Minister of Public Works to the Congress. The Spanish ladies had been requested to wear their

[1] Address, in part, given before the American Institute of Mining and Metallurgical Engineers, Los Angeles, California, section, November 30, 1926.

mantillas, shawls, and combs to this affair, and they made certainly a beautiful sight. At this event speech-making to a large extent could not be avoided, as one member from each of the 52 countries made a speech of thanks. The banquet room being so large, it was not even noticed by two of the speakers at opposite ends, one speaking in French, and the other in Dutch, that they made their remarks at the same time, until laughter from the middle of the banquet room made them both sit down at once, before they had finished.

Pleasing features of this Congress were the official excursions arranged by the organization committee. Some of the excursions commenced as early as three weeks before the beginning of the Congress, and some ended more than two weeks after adjournment. Everything worth seeing from the geological and mining engineering standpoint in Spain, Morocco, the Canary and the Balearic islands was included.

The writer feels safe in making the statement that although up to date no petroleum in commercial quantities has been found in any of the wells drilled in Spain, it is his opinion that petroleum in commercial quantities is likely to be found if wells in proper localities are drilled deep enough. It is probable that the laws referring to petroleum exploitation may have to be changed in order to induce capital to go to the necessary large expenditures in searching for and developing petroleum resources.

The two most interesting excursions during the sessions of the Congress itself were the one to Toledo and to the Escurial. In Toledo nearly all invested in Spanish shawls and mantillas and engraved cutlery, which are made in the town. At the immense castle of Escurial, access was given us to all of the private rooms, and one can form a fairly good idea of the character of the mysterious King Phillip II from the surroundings in which he lived.

After Congress the writer visited Barcelona and the salt and potash works at Suria and Cardona. At Barcelona one hears little Spanish among the population, as its language is Catalonian, though they all speak Spanish as well. The night life of Barcelona is even more striking than in Madrid.

The principal purpose of any international scientific congress is to bring men of all nationalities together, so that they may get personally acquainted with one another and discuss their mutual problems in order to avoid duplication of efforts. Such meetings obliterate to a great extent the bad feelings which for one reason or another have been created, and give all reasonable men a more charitable outlook toward life in nations other than their own. Along the lines of petroleum geology, with the exception of the papers published by Spanish geologists relating to Spain itself, little was read. The personal acquaintances, however, made among the geologists present from many foreign countries, which enabled one to discuss petroleum and other resources in all parts of the world, in connection with all branches of geology, are full recompense for the time spent at the Congress. After the Congress, the writer visited France and Germany and went underground to a depth of 200 meters, about 655 feet, in the oil fields of Pechelbronn, north of Strassburg, and saw how oil can be profitably mined.

The place where the next International Congress will be held has not yet been decided. Capetown, in South Africa, and Prague, the capital of Czechoslovakia, were applicants.

It has been the custom of the International Geological Congress to publish complete monographs on one particular mineral. The one held in Stockholm took iron for its subject, and the one held in Toronto, coal. These monographs are standard, at least up to date of publication, and are very useful for reference. The writer would like to see

petroleum selected as the next subject, and Washington, D.C., as the next meeting place after Capetown or Prague.

F. O. MARTIN

LOS ANGELES, CALIFORNIA
December, 1926

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

Julia A. Gardner, Washington, D.C.
L. W. Stephenson, David White, G. B. Richardson

Eugene T. Hancock, Bucharest, Roumania
H. F. Crooks, I. P. Voitesti, Ray P. Walters

Oscar Hatcher, Cartagena, Colombia, South America
W. B. Wilson, Thos. W. Leach, Robert E. Garrett

George Sherwood Hume, Ottawa, Ontario, Canada
Carroll H. Wegemann, Glen M. Ruby, Oliver B. Hopkins

Louis W. Leyds, The Hague, Holland
Angus McLeod, Roy R. Morse, E. F. Davis

Thomas George Madgwick, London, England
Sidney Powers, V. R. Garfias, L. C. Snider

Hastings Moore, Tulsa, Okla.
A. F. Truex, A. L. Beekly, R. S. McFarland

Innokenti Pavlovich Tolmachoff, Pittsburgh, Penn.
Roswell H. Johnson, R. E. Somers, L. G. Huntley

Max K. H. Bauermann, The Hague, Holland
F. A. A. van Gogh, Ernest Ganz, O. Dreher

John Owen Bryant, Tulsa, Okla.
Robert E. Garrett, Russell S. Tarr, A. W. Lauer

Bruce L. Clark, Berkeley, Calif.
William S. W. Kew, E. F. Davis, A. O. Woodford

William H. Elson, Tulsa, Oklahoma
H. M. Scott, Robert E. Garrett, L. L. Foley

Frank Escher, The Hague, Holland
F. A. A. van Gogh, O. Dreher, T. Erb

Verne A. Fagin, Maracaibo, Venezuela, S. A.
C. M. Crebbs, P. E. Nolan, Charles R. Rider

William E. Horkey, Tulsa, Okla.
H. E. Rothrock, T. E. Weirich, R. J. St. Germain

Walter T. Keller, Tampico, Mexico
D. Trumpy, Alfred P. Frey, R. D. Vernon

Eric O. Macpherson, Wellington, New Zealand
Frederick G. Clapp, Chester W. Washburne, Charles E. Decker
Earl N. McCormack, New York, N.Y.
David Donoghue, F. B. Plummer, Theodore A. Link
Launcelot Owen, London, England
A. K. McGill, A. Faison Dixon, A. H. Garner
George H. Shelton, Alamogordo, New Mexico
Charles T. Kirk, James E. Hoover, Burr McWhirt
Joseph H. Show, Coalinga, Calif.
J. A. Taff, H. J. Steiny, William S. W. Kew
Rex M. F. Townsend, New York, N.Y.
A. Faison Dixon, A. H. Garner, Albert D. Brokaw
Joseph M. Wanenmacher, Steubenville, Ohio
K. C. Heald, Edward T. Bleecker, W. I. Robinson
Harold J. Wasson, New York, N.Y.
Edwin B. Hopkins, D. R. Semmes, H. Harper McKee
Albert W. Weeks, San Antonio, Tex.
C. Max Bauer, W. H. Twenhofel, Ernest Guy Robinson

FOR ASSOCIATE MEMBERSHIP

Earl Armbruster, Los Angeles, Calif.
Howard W. Kitson, John G. Burtt, Roy R. Morse
Georg Tuchel, New York City, N.Y.
W. A. J. M. van der Gracht, Carroll H. Wegemann, John F. Weinzierl
Charles Russell Bickel, Tulsa, Okla.
A. F. Truex, L. G. Welsh, C. D. Stephenson
Cecil La Marr Chatman, Cisco, Tex.
Dave P. Carlton, E. Holman, R. H. Goodrich
James F. Gibbs, Norman, Okla.
Charles E. Decker, V. E. Monnett, A. J. Williams
Norman Hardy, Los Angeles, Calif.
William S. W. Kew, E. M. Butterworth, George M. Cunningham
Raymond A. Moore, Tulsa, Okla.
C. G. Carlson, R. S. McFarland, A. F. Truex
Edwin M. Reed, Tulsa, Okla.
E. G. Allen, Fanny Carter Edson, Burr McWhirt
Robert Barling, Wichita Falls, Tex.
H. B. Fuqua, David Donoghue, C. E. Yager
August J. Bauernschmidt, Jr., Dallas, Tex.
Samuel H. Williston, C. R. Nichols, F. H. Lahee
Darwin M. Benedum, San Antonio, Tex.
W. C. Spooner, S. P. Borden, Shirley L. Mason
Morris F. Bohart, Fort Worth, Tex.
W. M. Winton, Gayle Scott, F. B. Plummer
W. F. Bowser, Fort Worth, Tex.
W. M. Winton, Gayle Scott, F. B. Plummer
Sherwood Buckstaff, Ardmore, Okla.
W. Dow Hamm, T. K. Harnsberger, P. H. Keller

Margaret C. Carpenter, Fort Worth, Tex.
F. B. Plummer, W. M. Winton, Gayle Scott
Robert L. Cassingham, Enid, Okla.
Charles E. Decker, V. E. Monnett, G. E. Anderson
John W. Clark, Cisco, Tex.
F. B. Plummer, David Donoghue, Paul L. Applin
W. Storrs Cole, Tampico, Mexico
Ellis A. Hall, O. A. Larrazolo, Jr., Walt M. Small
Roland E. Collons, Tulsa, Okla.
F. B. Plummer, Albert E. Oldham, Donald C. Barton
Laverne Decker, Ardmore, Okla.
R. A. Birk, Charles E. Clowe, C. W. Tomlinson
Everett J. Dewees, Dallas, Tex.
Leon J. Pepperberg, R. B. Whitehead, H. B. Hill
Earl Emendorfer, Toronto, Canada
Oliver B. Hopkins, Arthur Iddings, Theodore A. Link
Russell W. Grimes, Abilene, Tex.
W. H. Whittier, Ulrich R. Laves, Luther H. White
Gordon W. Heid, Alameda, Calif.
Paul L. Henderson, William S. W. Kew, E. M. Butterworth
Walter W. Henderson, Tulsa, Okla.
Harry T. Wright, Frank A. Herald, M. J. Munn
Ralph Ilsley, Dallas, Tex.
F. H. Lahee, Samuel H. Williston, Leon J. Pepperberg
William E. Jenkins, Fort Worth, Tex.
F. B. Plummer, Albert E. Oldham, Donald C. Barton
Hugo R. Kamb, Tulsa, Okla.
Clinton R. Stauffer, W. H. Emmons, L. L. Foley
James M. Kirby, Los Angeles, Calif.
Paul L. Henderson, William S. W. Kew, E. M. Butterworth
Howard M. Kirk, Laredo, Tex.
Theodore Chapin, V. R. Garfias, Harold E. Boyd
Leonard F. McCollum, San Antonio, Tex.
E. H. Sellards, L. T. Barrow, George D. Morgan
Richard G. Reese, Los Angeles, Calif.
Wilson C. Giffin, Glenn D. Robertson, Carroll M. Wagner
Dana Russell, Claremont, Calif.
A. O. Woodford, William S. W. Kew, George M. Cunningham
Frank J. Stangl, Fort Worth, Tex.
W. M. Winton, Gayle Scott, F. B. Plummer
Clement A. Weintz, Golden, Colo.
Max W. Ball, F. M. Van Tuyl, W. A. Waldschmidt
Edward V. Winterer, Berkeley, Calif.
Charles E. Meek, E. L. Ickes, Roy R. Morse

FOR TRANSFER

B. F. Robinson, Tulsa, Okla.
J. C. Ross, Wm. H. Foster, L. L. Foley

Pedro I. Aguerrevere, New York, N.Y.
Theodore Chapin, Harold E. Boyd, V. R. Garfias
Horace M. Bayer, Eastland, Tex.
H. B. Fuqua, David Donoghue, C. E. Yager
Olin G. Bell, Laredo, Tex.
Wallace E. Pratt, Eugene Holman, Alexander Deussen
Francis W. Dakin, Oklahoma City, Okla.
M. E. Carpenter, R. A. Conkling, L. E. Trout

THE A.A.P.G. AND THE PETROLEUM DIVISION OF THE A.I.M. & M.E.

The meeting of the Petroleum Division of the American Institute of Mining and Metallurgical Engineers held in the United Engineering Building, 29 West Thirty-ninth Street, New York, on February 14–17, embraced several sessions. Sessions and presiding officers were: 1, General session—F. Julius Fohs; 2, Refining technology—Charles H. Osmond; 3, Corrosion—Frank N. Speller; 4, Production engineering—T. E. Swigart; 5, Production and development—James H. Gardner; 6, Petroleum economics—Joseph E. Pogue; 7, Round table discussion of petroleum engineering problems—H. C. George; 8, Round table discussion of petroleum engineering research problems—W. E. Wrather.

The following officers were nominated for the petroleum division for 1927:

Chairman, John M. Lovejoy, vice president, Amerada Petroleum Corporation, Tulsa, Oklahoma.

Vice chairman for refinery engineering, Walter Miller, vice president, Marland Refining Company, Ponca City, Oklahoma.

Vice chairman for production engineering, J. B. Umpleby, vice president, Goldelline Oil Corporation, Oklahoma City, Oklahoma.

Associated vice chairman for producing engineering, T. E. Swigart, production engineer, Shell Oil Company of California, Los Angeles, California.

Vice chairman for production, W. E. Wrather, consulting geologist, Dallas, Texas.

Associate vice chairman for production, Joseph Jensen, Associated Oil Company, Los Angeles, California.

Vice chairman for transportation engineering, F. K. Haskell, manager, Empire Pipe Line Company, Bartlesville, Oklahoma.

Vice chairman for economics, Joseph E. Pogue, consulting geologist, New York City.

Seventy-five per cent of the presiding officers and nominees are members of the A.A.P.G.

The following is Article II from our Association constitution:

The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and improvements in the methods of winning these materials from the earth; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous men posing as petroleum geologists.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

At the University of Texas PROFESSOR WILLIAM MORRIS DAVIS has completed his service as visiting professor in geology for the fall term. During the winter term PROFESSOR G. D. HARRIS, of Cornell University, as visiting professor of geology, is giving a course in Tertiary geology and paleontology.

M. FERDINAND CANU, of Versailles, France, leading authority on fossil micro-organisms in Europe, has intrusted the Smithsonian Institution with his private collection of fossil invertebrates from France and particularly from the Paris basin, which he has spent fifty years in gathering. M. Canu made the gift through R. S. BASSLER, paleontologist of the National museum under the Smithsonian, with whom he has collaborated extensively since 1910 in working out geological horizons for the Atlantic and Gulf States.

The WEST TEXAS GEOLOGICAL SOCIETY recently met in San Angelo and elected the following officers: H. P. BYBEE, president, V. E. COTTINGHAM, vice-president, and MRS. J. BEN CARSEY, secretary-treasurer. Adoption of a committee report presented by EDGAR KRAUS provides for a series of co-operative field investigations with students of the University of Texas and E. H. SELLARDS, associate director of the Bureau of Economic Geology at Austin. Eventually this work will be carried from all directions toward the center of the great salt basin.

HARRY H. NOWLAN and Miss Miriam Bernice Wear announce their marriage on Saturday, December 4, 1926, at Tulsa, Oklahoma. Mr. and Mrs. Nowlan are at home at 1631 East Fifteenth Street, Tulsa, Oklahoma.

B. F. HAKE is employed by the Marland–Hudson Bay Oil Company.

W. DANA MILLER arrived in Maracaibo, Venezuela, in January, as manager for the Esperanza Petroleum Corporation.

H. C. MCLAUGHLIN is a member of the geological department of the Lone Star Gas Company of Dallas.

W. E. DUNLAP is chief geologist of the Richfield Oil Company of Los Angeles.

D. DALE CONDIT, whose address until recently was care of Whitehall Petroleum Corporation Ltd., Shillong, Assam, India, is now located with the corporation at 53 Parliament Street, London, S.W.I., England.

C. W. STUDT is chief geologist for the Union Gas Corporation, Commercial National Bank Building, Independence, Kansas. A recent item gave his address as 120 Broadway, New York City. This was an error. Mr. Studt spent part of September and October in Alberta, Canada, on leave from the Union Gas Corporation, while he represented the Canadian Western Natural Gas, Light, Heat, and Power Company in its recent gas-rate case before the Alberta Public Utilities Commission. In this connection Mr. Studt made a first-hand study of the gas fields of Alberta and computed their gas reserves.

WILLIS STORM, secretary-treasurer of the DALLAS PETROLEUM GEOLOGISTS, announces the following speakers for the regular meetings of the society which are held

every other Monday night, twice a month, in the Baker Hotel: FRANK KENDRICK, a selected subject; W. E. WRATHER, "The International Geological Congress"; CARL YOUNG, "The A. P. I. Standardization Program"; LEON J. PEPPERBURG, a selected subject; A. S. FIELD or E. G. ALLEN, "New Ideas of Oil Recovery"; F. H. LAHEE, a selected subject; B. C. RENICK, "The Carlsbad, N.M., District"; R. B. WHITEHEAD, a selected subject; E. H. TOLLEFSON, "New Fields in the Permian Basin of West Texas"; H. B. HILL, a selected subject; and E. W. SHULER, a selected subject.

JOHN R. SUMAN, formerly vice-president and general manager of the Rio Bravo Oil Company, is now a director and executive officer in charge of production for the Humble Oil & Refining Company.

E. H. SELLARDS, associate director of the Bureau of Economic Geology of the University of Texas, at Austin, has announced a bound volume of the Bureau publications for 1926 containing the following: *Bulletin 2607*, "The San Angelo Formation and the Geology of Foard County," by J. W. BEEDE and D. D. CHRISTNER; *Bulletin 2609*, "The Southwest Earthquake of July 30, 1925," by J. A. UDDEN; *Bulletin 2612*, "Foraminifera of the Cretaceous of Central Texas," by DOROTHY OGDEN CARSEY; *Bulletin 2644*, "The Foraminifera of the Midway Formation," by HELEN JEANNE PLUMMER; and *Bulletin 2645*, "The Gueydan, a New Middle-Tertiary Formation from the Southwestern Coastal Plain of Texas," by THOMAS L. BAILEY. The cost of this cloth-bound volume is $4.00.

On December 13 and 14, PROFESSOR W. M. DAVIS, of Harvard University, visited Texas A. and M. College at College Station and made addresses both to the students and to the faculty. His subjects were "Glacial Sculpture of Mountains," "The Origin of the Great Basin Ranges," and "The Natural History of Goodness."

JAMES H. HANCE, of Texas A. and M. College, attended the Madison meeting of the Geological Society of America.

DARWIN BENEDUM, of San Antonio, Texas, spent a part of October and November in Shreveport, Louisiana, in the interest of the Benedum-Trees Oil Company.

ROY T. HAZZARD has resigned from the Standard Oil Company of California to go with the Gulf Refining Company. He made the Shreveport, Louisiana, office temporary headquarters during December.

H. G. WEEKS spent the holidays in Wisconsin and attended the Geological Society of America meeting at Madison.

CLYDE M. BENNETT, vice-president of the Louisiana Oil Refining Corportaion, returned to Shreveport for the holidays, after a two months' inspection trip of the company's properties in Trinidad and Venezuela.

JOHN M. MUIR recently arrived in Bagdad, where he takes the duties of senior geologist for the Turkish Petroleum Company. Mr. Muir had been connected with the Corona (Dutch Shell) in Mexico since 1913. He was chief geologist in 1925 and 1926.

ARTHUR H. NOBLE, formerly with the Turkish Petroleum Company for many years, has been made assistant manager for the Dutch Shell in Borneo. He preceded Mr. Muir as chief geologist of the Aguila-Corona in Mexico.

R. L. CLIFTON, chief geologist for the Champlin Refining Company, is president and B. B. ZAVOICO, subsurface geologist for the Sinclair Oil & Gas Company at Enid, is secretary-treasurer of the newly formed GEOLOGICAL SOCIETY OF NORTHWESTERN OKLAHOMA. The society meets on the first Wednesday of each month in the Oxford Hotel, Enid.

Members of the society are engaged in geological work in Noble, Kay, Logan, Kingfisher, and adjacent counties.

VAUGHN W. RUSSOM and Miss Juanita Hostetler were married on Thursday, December 23, 1926, at Winfield, Kansas. Mr. and Mrs. Russom are at home at 619 North Aydelotte, Shawnee, Oklahoma.

A. B. BARTLETT, state geologist of Wyoming, claims there are 2,000,000 tons of potash in southwestern Wyoming.

R. A. DALY, head of the department of geology of Harvard University, has written a luminous book, *Our Mobile Earth*. He discusses Wegener's theory of continental drift and refers to previous conceptions of such a theory by FRANK B. TAYLOR and EDWARD SUESS.

C. D. STEPHENSON, formerly chief geologist of the C. J. Wrightsman interests, is chief geologist of the Galt-Brown Company, Alexander Building, Tulsa, Oklahoma.

W. B. GRAHAM and Miss Robertelle Hamiter were married at Little Rock, Arkansas, November 23, 1926.

A. C. CAVENDER and Miss Lillian Hyde were married at Vicksburg, Mississippi, December 20, 1926.

At a meeting of the Rocky Mountain Geologists held in Denver, Colorado, H. A. STEWART, of the Texas Company, was elected president, ROSS L. HEATON was elected vice-president, T. H. OLDS, second vice-president, and R. C. BREHM, secretary and treasurer.

The areal geological map of Oklahoma may be purchased from the U.S. Geological Survey for $1.50.

Subsurface structure contour maps of northeastern Oklahoma mapped on the Bartlesville sand, "Mississippi lime," and Wilcox sand, prepared by W. T. THOM, JR., with the co-operation of the Oklahoma Geological Survey, may be procured free from the U.S. Geological Survey.

CLARENCE S. ROSS, of the U. S. Geological Survey, has developed a new technique for grinding thin sections of unconsolidated material without the use of water. He has found that clay may consist of one or more of five minerals: montmorillonite, beidellite, micaceous halloysite, halloysite, and kaolinite.

L. W. STEPHENSON, of the U. S. Geological Survey, is contributing a chapter on the geology of the Coastal Plain to a new book, "The Geology of North America," which is being edited by RUDOLF RUEDEMANN. Dr. Stephenson published his presidential address of the Washington Academy of Sciences in the *Journal* of the Academy for December, the subject being the Coastal Plain. His map shows some interesting tectonic lines.

FRANK L. HESS, of the U. S. Geological Survey, has submitted for publication by the Survey a report on "Oölites in the Carlsbad Cavern, New Mexico."

H. W. HOOTS, of the U. S. Geological Survey, has prepared a paper on heavy minerals of the Pliocene (Etchegoin) rocks of the southern end of San Joaquin Valley, California.

PAUL V. ROUNDY and E. P. WOODRING, of the U. S. Geological Survey, have prepared a report on the Elk Hills oil field, California.

KIRTLEY F. MATHER, of Harvard University, prepared a report on the Elk Hills oil field last summer for President Coolidge at the authorization of Congress.

C. W. HONESS resigned from the Empire Gas & Fuel Company to accept a position with the Gypsy Oil Company, December 1.

S. C. ELLS is the author of a report on the bituminous sands of northern Alberta, published by the Mines Branch, Bureau of Mines, Ottawa, Canada, in November.

ROBERT T. HILL, one of the pioneers in geological work in the Southwest, is living at the Commodore Hotel, Los Angeles. Dr. Hill teaches at the Southern Branch of the University of California. On December 15, 1886, he first presented an outline of the Comanchean series of Texas before the Philosophical Society of Washington.

E. T. DUMBLE, pioneer geologist of the Southwest, died at Nice, France, in January.

W. P. HAYNES and H. F. CROOKS, of Paris, made a trip to southern Europe in November.

C. N. GOULD will conduct a geological trip through the Arbuckle Mountains and southern Oklahoma oil fields after the Tulsa meeting of the Association.

DAVID WHITE, K. C. HEALD, and E. DEGOLYER are members of the Central Petroleum Committee of the National Research Council.

WILLIS STORM, chief geologist of the Pandem Oil Company, has moved from Wichita Falls to Dallas.

R. D. MCCLURE has resigned from the Gulf Production Company to engage in consulting work at Corsicana, Texas.

H. B. FUQUA, of the Gulf Production Company, has been transferred from Wichita Falls to Fort Worth, where he is assistant to BEN C. BELT.

J. B. LOVEJOY is in charge of geological work for the Gulf Production Company at Wichita Falls, Texas.

I. R. SHELTON has joined the geological staff of the Atlantic Oil Producing Company at Wichita Falls.

H. J. PACKARD, chief geologist of the Continental Oil Company, is a frequent visitor at their Wichita Falls office, where they have taken over the properties of the Texhoma Oil & Refining Company.

IRVINE STEWART is chief geologist for the California Petroleum Corporation at Los Angeles.

S. V. WHITE is engaged in consulting work, with an office in the Staley Building, Wichita Falls, Texas.

MRS. PAUL APPLIN has moved to Fort Worth.

WILLARD L. MILLER, geologist for W. R. Ramsey of Oklahoma City, has re-examined the Jackson fault, Alabama.

FRANK PARSONS, consulting geologist, is living at Wichita Falls, where he has an office in the Staley Building.

H. B. HILL, of the Bureau of Mines at Dallas, has prepared a report on Powell.

The following geologists have been in successive charge of the Tulsa office of the Sinclair Oil & Gas Company since 1916: J. ELMER THOMAS, HENRY HINDS, STANLEY C. HEROLD, A. A. HAMMER, JON A. UDDEN, J. Q. MYERS, and W. C. GISH. Those who represented the Sinclair-Gulf in Fort Worth were L. G. DONNELLY, H. H. MCKEE, and JON A. UDDEN.

C. P. McGAHA is geologist for Murchison & Fain, at Wichita Falls.

C. R. McCOLLOM, W. E. PRATT, MAX W. BALL, and LUTHER H. WHITE presented papers on "The Nation's Petroleum Supply—a Geologic Analysis" at the American Petroleum Institute meeting in Tulsa, December 9.

J. E. EATON, consulting geologist of Los Angeles, published the "History of Los Angeles Basin Fields" in the *Oil and Gas Journal* for December 2, 1926.

"Petroleum Geology in Oklahoma," by SIDNEY POWERS, a history of the development and application of petroleum geology with respect to the petroleum industry, was published by the Oklahoma Geological Survey in January as a chapter of *Bulletin 40* on "Oil and Gas In Oklahoma."

A. E. OLDHAM, now with the Amerada Petroleum Corporation at Forth Worth, discovered the broad fold on which the Rycade Oil Corporation's Chittim well in Maverick County, Texas, was drilled. At 5,515 feet this well found 5,000,000 cubic feet of gas-spraying oil of composition like gasoline 1,200 feet below the top of the Trinity group. This is the first encouragement for commercial production in the Trinity in Texas, since its prediction by WALLACE E. PRATT in the *Oil Weekly*, July 30, 1926. The Chittim well is 17 miles east of Eagle Pass.

C. G. WILLIS was influential in locating the discovery well of the Marland Oil Company of California at Seal Beach.

W. H. SPICE, JR., resigned from the Marland Oil Company of Texas, at San Antonio, in November to accept a position with the Pan-American Petroleum & Transport Corporation, at Maracaibo, Venezuela.

W. T. THOM, JR., geologist in charge of the geology of fuels for the U. S. Geological Survey, published a paper, "Program of Researches in Oil Geology" in the *Oil and Gas Journal* for December 2, 1926.

"Interpretation of Productive Curves," by C. E. VAN OSTRAND, of the U. S. Geological Survey, a mathematical study of decline curves, was published in the *Oil and Gas Journal* for December 2, 1926.

JAMES H. GARDNER, of Tulsa, published in the *Oil and Gas Journal* for December 2 a paper entitled: "Progress Made in Petroleum Research."

WILLIAM WHEELER SHELDON is in charge of geological and field operations for the Sheldon Oil Company of Tulsa.

J. ELMER THOMAS gave a dinner in Tulsa October 2, 1915, which led to the meeting held January 8, 1916, in Norman and to the organization of this Association. There were twenty-seven geologists at the dinner, but the following are the only names on the list of those known to have been present. Will the others please communicate with Mr. Thomas, Fort Worth Club Building, Fort Worth, Texas, in order to complete the list? F. L. AURIN, EVERETT CARPENTER, F. JULIUS FOHS, J. H. GARDNER, BURTON HARTLEY, L. L. HUTCHINSON, LUCIAN WALKER, H. F. WRIGHT, A. W. McCOY, E. W. McCRARY, M. J. MUNN, C. W. SHANNON, C. D. SMITH, C. H. TAYLOR, M. M. VALERIUS.

C. C. CARLSON and Miss Gladys Ross, of Oklahoma City, were married December 23. They will be stationed during the winter at Lansing, Michigan, for the Sun Oil Company.

ED GEORGE has returned to the land department of the Amerada Petroleum Corporation at Shawnee, Okla.

C. N. VALERIUS was married to Miss Marguerite Behner of Jefferson City, Missouri, on December 24. Mr. Valerius is with the Sun Oil Company at Tulsa.

Officers of the TULSA GEOLOGICAL SOCIETY for 1927 are A. L. BEEKLY, president, G. C. POTTER, vice-president, E. O. MARKHAM, secretary-treasurer, W. R. HAMILTON, BURR MCWHIRT, and CONSTANCE EIRICH, members of the council.

E. C. MONCRIEF, chief geologist of the Derby Oil Company of Wichita, Kansas, is working at San Angelo.

JAMES M. DOUGLAS, geologist for the Union Oil Company in charge of their Rocky Mountain work, is now Venezuelan manager of the Union National Petroleum Company at Maracaibo. WILLIAM G. GALLAGHER, JR., has taken his place at Fort Collins, Colorado.

J. C. Ross, formerly with the Reiter-Foster Oil Corporation, is now geologist for the Sneed Royalty Company.

W. H. FOSTER, of Tulsa, and W. A. REITER, of Mexia, Texas, have resigned from the Reiter-Foster Oil Corporation.

D. C. BARTON published "The Gulf Coast Oil Fields of Southeast Texas and Southwest Louisiana" (17 pp.), in the *Internationale Bergwirtschaft* (Leipzig, Germany, June–July, 1926).

HENRY HINDS of the Pontapec Oil Company spent the winter in Venezuela.

A report on the oil activities of the Geological Survey of Brazil is available at the U. S. Department of Commerce, *Report 44341 Brazil.*

RALPH ARNOLD'S paper on "The Relationship of Geology to Development of Rocky Mountain Oil Fields," read before the Montana chapter of the Rocky Mountain Oil and Gas Association December 3, was printed in the *National Petroleum News*, December 15, 1926.

E. RUSSELL LLOYD, of Denver, has moved to Carlsbad, New Mexico.

N. P. ISENBERGER, of the Amerada Petroleum Corporation, has been transferred from Amarillo to San Angelo.

DR. ANSELMO WINDHAUSEN is professor of geology at the University of Cordoba, Argentina. He has published a structure contour map of the Comodoro Rivadavia oil field.

V. H. HUGHES, consulting geologist at Tulsa, is working in Missouri.

S. S. PRICE, of Tulsa, is vice-president of the Dixie Oil Company.

J. MARSHALL BROWN is geologist for the Philmack Oil Company at Fort Worth, Texas.

WALLACE RALSTON and E. B. WILSON have joined the Sun Oil Company at Dallas.

E. L. PORTS and D. R. SEMMES maintain an office at 213 Spencer Building, Cisco.

LEON E. ENGLISH is associated with R. D. Clancy of Dallas.

HERSCHEL H. COOPER is geologist for the Pan-American Petroleum Company in Tampico.

JOHN B. BLANCHARD is engaged in consulting work at Brownwood, Texas.

F. H. LAHEE, who went east to attend the New York meeting of the Association last November, has returned to Dallas, having recovered from an attack of influenza which detained him for five weeks in Washington, D.C.

Memorial

EDWARD DANA NOLAN

Edward Dana Nolan, who for many years had been an active figure in geological circles of the oil industry of California, died at San Francisco, California, on September 5, 1926, at the age of thirty-six years.

His early life was spent near San Luis Obispo, where his parents were identified with the early history of that section of California.

He graduated from Stanford University in geology and mining in 1911. His first employment was with the Associated Oil Company as a geologist. From 1912 to 1914 he was associated with the General Asphalt Company in Trinidad, B.W.I. Upon his return to the United States in 1914 he became geologist for the Canadian Montana Company, whose operations centered in Montana and Alberta, Canada.

In 1916 he became identified with the Shell Company of California. In the early part of 1920 he went to the General Petroleum Corporation as chief geologist, which position he held until the time of his death. During this period his activities took him over a large part of western United States, Canada, and Alaska.

The writer knew him more than twenty years and held him in high regard for his many excellent qualities and particularly because of his keenness of mind and wide experience.

He is survived by his mother, brother, and widow. The latter is known as Neva Gerber in the film colony.

J. E. Elliott

JAMES FURMAN KEMP

James Furman Kemp, head of the department of geology at Columbia University, died suddenly at his home in Great Neck, Long Island, November 17, 1926. Professor Kemp was apparently in good health up to the day of his death and was stricken while preparing to meet his usual classes. He addressed a sectional meeting of the American Institute of Mining Engineers two days before his death.

Dr. Kemp was born in 1859, graduated at Amherst in 1881, and earned his mining engineering degree at the School of Mines, Columbia University, in 1884. After two years' study in Germany he became an instructor at Cornell University, where he remained until 1891. Then he returned as adjunct professor to Columbia University, where the remainder of his life was centered.

From the time of his graduation at Columbia, Kemp was primarily interested in ore deposits. As geologist on the Federal and New York State surveys, he made many important contributions to metalliferous economic geology. Largely through his efforts the department at Columbia was for many years pre-eminent in the training of students of ore deposits, and his more important publications dealt with crystalline rocks and their associated ores. His *Ore Deposits of the United States and Canada* was this country's first important text in economic geology. At the time of his death the book was being revised to include the non-metallic phases of economic geology also. Kemp's *Handbook of Rocks*

has long been a guide to the field geologist, and his bibliography contains more than two hundred articles on economic and theoretical geology.

Dr. Kemp's scientific achievements brought him many honors, including the presidencies of the Geological Society of America, the American Institute of Mining Engineers, the Mining and Metallurgical Society of America, and the New York Academy of Sciences. He was a member of many other scientific societies and organizations, and was also a corresponding member of several foreign geological societies. Additional honors included the gold medal of the Mining and Metallurgical Society and the much coveted membership in the National Academy of Sciences.

Following a nervous breakdown in 1915, Dr. Kemp went to the mid-continent field for the sake of his health. His eager scientific spirit would not permit him to rest, and he was soon working in Tulsa as a consulting geologist. Although a member of the American Association of Petroleum Geologists since 1917, he presented no formal papers to the Association. At the Oklahoma City meeting in 1918 he gave an address on "Geology Applied to Engineering." He also published "Observations on a Florida Sea Beach with Reference to Petroleum Geology," in *Economic Geology*, in 1919. Recovered in health, he returned to New York City in 1917 and resumed his work at Columbia University.

Professor Kemp's scientific contributions were equaled by few men, yet perhaps his greatest gift to his science was the inspiration and assistance he gave so freely to all his students and associates. Known and loved for a third of a century by Columbia students as "Uncle Jimmy," his keen, analytical comments and his friendly counsel were freely given to all his foster-children. He taught not only the principles of geology but also the precepts of scientific accuracy, honesty, and earnest search for truth, regardless of preconceived ideas and preferences. He was ever an example and a warm personal friend to his former students, in whom he took a deep interest which followed them beyond the classroom throughout their lives.

James Furman Kemp is gone from us in person, but his spirit lives on in the men he trained and the influence he gave to geology.

R. S. KNAPPEN